SECTION 12. KEY SCENARIOS AND FINDINGS

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SECTION 12. KEY SCENARIOS AND FINDINGS

12.1 Introduction to Scenarios and Findings

Several key scenarios were used to assess the achievement and maintenance of the Chesapeake water quality standards for dissolved oxygen, chlorophyll, and clarity (USEPA 2003a, 2003b). One key scenario was the 2010 Tributary Strategy Scenario, which encompasses the estimated 2010 management conditions, land use, and human and animal populations under conditions of the 2003 allocations' tributary strategies. Other key scenarios included a 2010 No-Action Scenario and an E3 Scenario, which, together, formed the basis for the 2010 TMDL Allocation. Scenarios were also developed to represent key Chesapeake Bay Program (CBP) years like the 1985 Scenario, corresponding to a period of highest nutrient and sediment loads to the Bay, and the 2009 Scenario representing current conditions. The lowest loads to the Bay were simulated by the All Forest Scenario, which estimates the nutrient and sediment loads under an all-forested condition in the watershed.

This section describes in detail the development of these key scenarios and their estimated loads. It also describes elements of scenario operations, which are distinct from the calibration operations of the Phase 5.3 Model. Initial findings of climate change effects on flow and loads to the Chesapeake conclude the section.

The climate change analysis is a preliminary assessment of climate change effects on the Chesapeake Bay using an earlier version of the Phase 5 Chesapeake Bay Watershed Model (Phase 5.2) and tools developed for EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) 4 system including the Climate Assessment Tool (CAT). Flows and associated nutrient and sediment loads were assessed in all river basins of the Chesapeake Bay with three key climate change scenarios reflecting the range of potential changes in temperature and precipitation in the year 2030. The three key scenarios came from a larger set of 42 climate change scenarios that were evaluated from 7 Global Climate Models (GCMs), 2 scenarios from the Intergovernmental Panel on Climate Change (IPCC) SRES (Special Report on Emissions Scenarios) storylines, and 3 assumptions about precipitation intensity in the largest events.

In 2017 a more complete analysis of climate change effects on TMDL nutrient and sediment loads will be made during a mid-course assessment of Chesapeake TMDL progress, as called for in Section 203 of the *Chesapeake Executive Order* (Office of the President 2009). (http://executiveorder.chesapeakebay.net/EO/file.axd?file=2009%2f8%2fChesapeake+Executive+Order.pdf). The Executive Order directs the assessment of "the impacts of a changing climate on the Chesapeake Bay and developing a strategy for adapting natural resource programs and public infrastructure to the impacts of a changing climate on water quality and living resources of the Chesapeake Bay watershed."

A subsequent *Executive Order Strategy* (EPA 2010) (http://executiveorder.chesapeakebay.net/file.axd?file=2010%2f5%2fChesapeake+EO+Strategy%20.pdf) calls for ensuring the "TMDL allocations account for climate change effects, and that EPA and USGS will work in conjunction with the states to conduct an analysis by 2017 to consider accounting for uncertainties of climate change in TMDL allocations." Because the TMDL nutrient and sediment allocation are caps, any increases in loads due to climate change will need to be offset by further management action to ensure the Chesapeake water quality standards are achieved.

12.2 Difference between Phase 5 Calibration and Scenario Mode of Operations

The Phase 5.3 Model is configured in two different operational modes—calibration mode and scenario mode. Differences between the Phase 5.3 calibration and scenario operations are the input data sets, simulation period, and the output time-scale. The Phase 5.3 calibration is run using variable input data sets in an attempt to best represent the observed flow and concentrations of nutrients and sediment in the rivers.

The calibration operation is a continuous run over the entire simulation period from 1984 to 2005 and is done to calibrate the model to observed flow and water quality data. That involved changing the estimated Phase 5.3 land use and best management practices (BMPs) annually as they occurred over the two-decade simulation period. Point source loads were input monthly over the two-decade time-series, and atmospheric deposition was also varied over the simulation period to best represent the loads as they occurred. The Phase 5.3 calibration output is calculated daily, e.g., mean daily flows and mean daily concentrations (Figure 12-1).

In comparison, in the scenario operation mode the Phase 5.3 Model is run for a 10-year hydrology simulation period from 1991 to 2000 and uses a constant representational input data set for each scenario. For example, if the 1985 year was simulated, the 1985 point source flows, BMPs, populations, atmospheric deposition, and all other aspects of the simulation would be used. Doing so provides a representation of the 1985 conditions over a 10-year hydrology from 1991 to 2000. The 1991–2000 10-year hydrology was decided by the CBP states to be an average decadal flow and load condition.

The scenario outputs are not compared with observed data as in the case of calibration operations. Scenario outputs are summarized on a 10-year annual average basis. Scenario outputs are compared against other scenarios to evaluate different management options and conditions in the watershed (Figure 12-2).

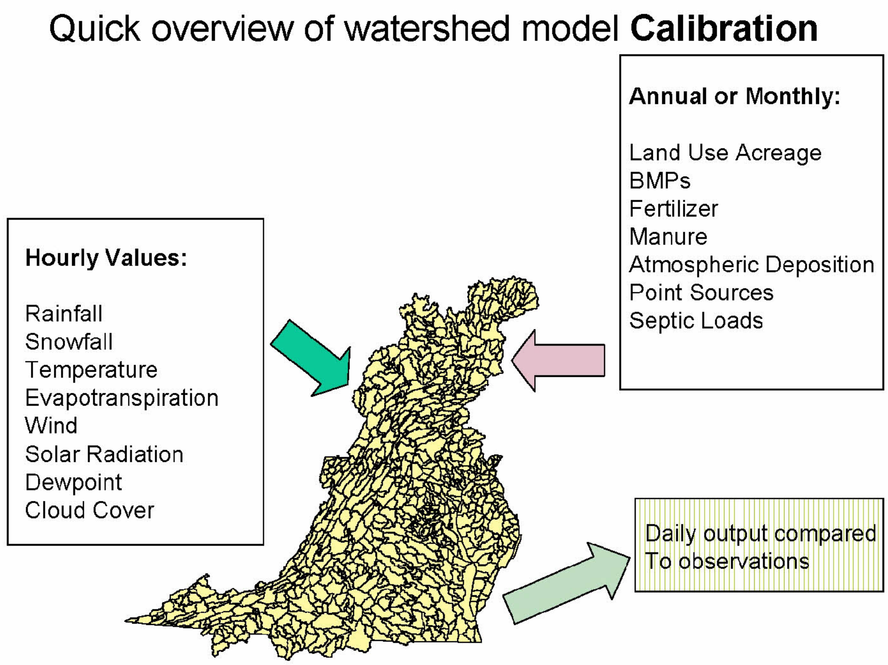


Figure 12-1. Chesapeake Bay Model Phase 5.3 operations in calibration mode.

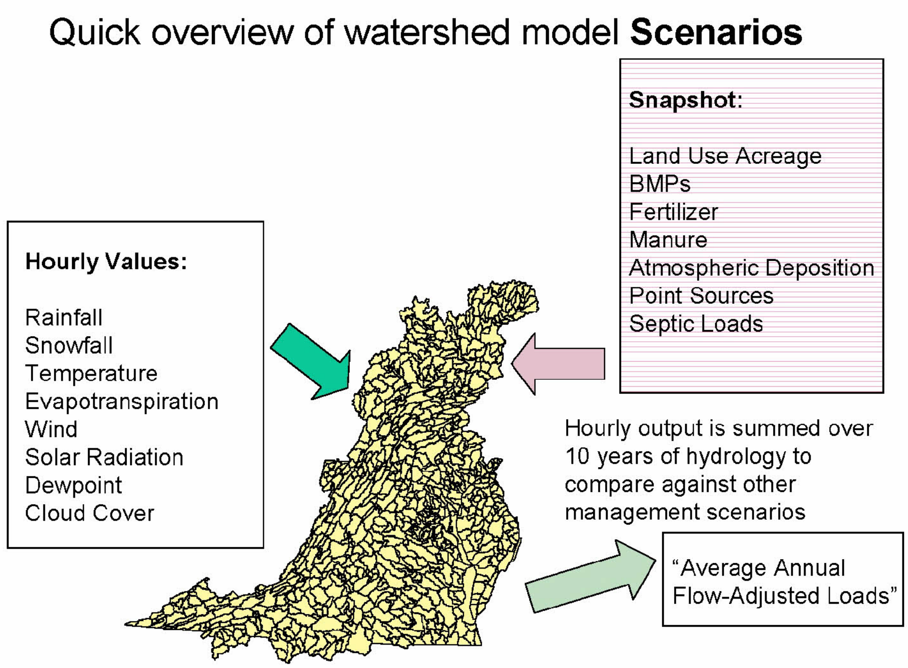


Figure 12-2. Chesapeake Bay Model Phase 5.3 operations in scenario mode.

12.3 Transport and Delivery Factors

Transport factors are the fractional change in load in a river-segment. In each river-segment, the simulated load is attenuated by denitrification of nitrate, the settling of particulates, or uptake of nutrients by algae including periphyton. In most cases of flow and river conditions, the transport factors are less than one. In some cases, where high flows led to scour sediment and the sediment bed stores of phosphate and ammonia, the transport factors of sediment and nutrients can be greater than unity.

In contrast, delivery factors for nutrients and sediment are the product of all the sequential river-segments in a basin between a segment and the tidal waters of the Chesapeake Bay. That represents the fractional change in load from the edge-of-stream to tidal water for any segment. The delivery factors for total nitrogen (TN) and total phosphorus (TP) are shown in Figure 12-3. Transport and delivery factors are unitless.

Delivery factors quantify the watershed attenuation of nutrient and sediment loads in the streams because of the hydrology regimen and anthropogenic processes such as BMPs. Like the transport factors, in periods of high flow, the delivery factors can be greater than one.

Delivery and transport factors change between scenarios as the nutrient loads change. Often, that is because of nutrient limitation, as management action can control one nutrient more than another. In the riverine simulation, just as in actual rivers, that tends to drive simulated concentrations toward nutrient limitation. Once nutrient concentrations fall below the Michaelis-Menten constants for algal growth, which are specified in the user-supplied HSPF constants (Bicknell et al. 1997; 2001; Donigian et al. 1984; Johanson et al. 1980), algal growth and nutrient uptake decreases, allowing more of the nonlimited nutrient to be transported through the river-segment.

This is shown in Figure 12-4, which plots the delivery factors for a high load scenario, the 1985 No-Action Scenario, against the delivery factors for a low load scenario, the E3 Scenario (both of those scenarios are fully described later in this section). Note that those are the delivery factors for all the Phase 5.3 river-segments and that the delivery factors range from zero to one. A delivery factor approaching zero would typically be that of a river-segment far up in the watershed where considerable attenuation can occur. Delivery factors approaching one are typically for river-segments close to or adjacent to the tidal Bay where most of the load would be delivered unattenuated. The one-to-one line is shown in red and is used as a spatial reference in Figure 12-4.

In all cases, the delivery factor of the E3 scenario is greater than the 1985 No-Action Scenario. That is because the E3 loads are less, resulting in nutrient limitation in some places and times in the rivers. While the E3 loads delivered to the Bay are much lower than the 1985 No-Action loads, the portion attenuated in the rivers in the E3 Scenario is relatively less than that of the 1985 No-Action Scenario.

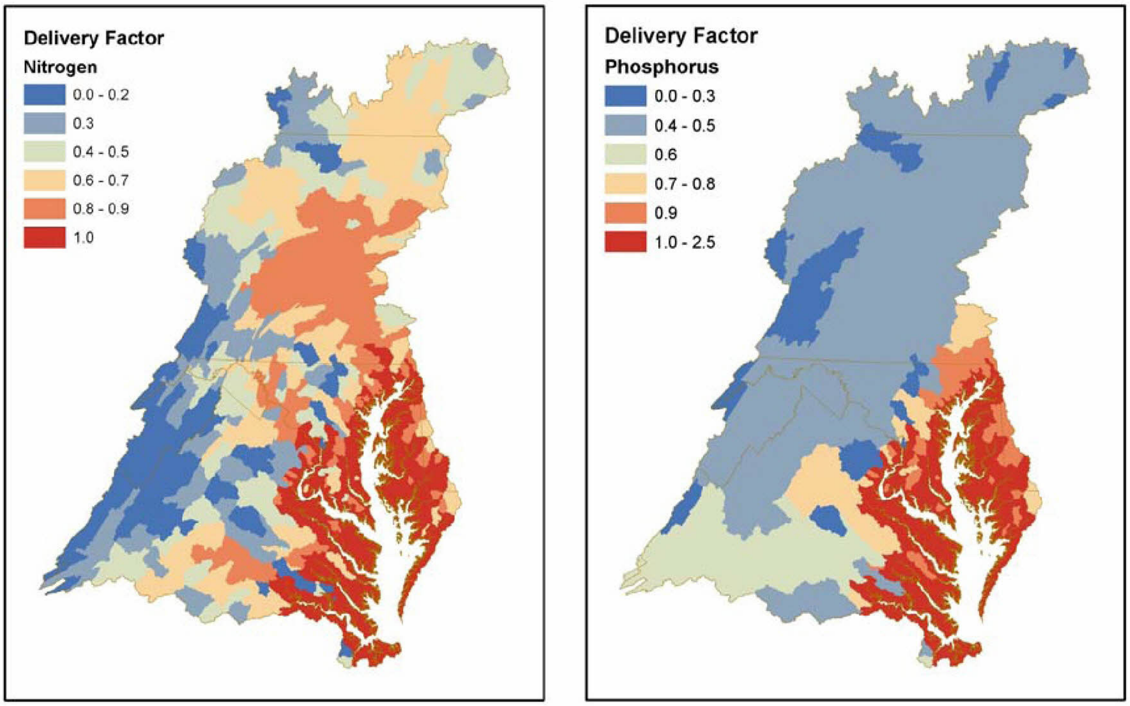


Figure 12-3. Chesapeake Bay Model Phase 5.3 delivery factors.

Loads of nitrogen are non-conservative as nitrogen is removed from the watershed by denitrification. Phosphorus, on the other hand, is conservative. Phosphorus and suspended sediment generally settles to the bottom sediments in low and average river flows but is transported by large storm flows through the watershed.

Rather than calculating yields for phosphorus and sediment on the basis of monitoring data, which can be greater or less than unity depending on the presence or absence of large storms, a constant delivery factor above reservoirs and other large impoundments was assigned as the waterbodies are effective at trapping phosphorus and sediment. That is applied only in the scenario mode of operations when the estimated nutrient and sediment loads are attributed to sources using delivery factors. The average delivery factor for the entire 1985–2005 simulation period was assigned for phosphorus and sediment for all land uses in river-segments above a reservoir or large impoundment. That is represented in Figure 12-5. The Lake Murburg reservoir is in the Susquehanna and basin and the Liberty and Pretty Boy reservoirs are in the West Chesapeake Basin. Note that those reservoirs have a lower delivery factor because of the high attenuation of sediment and phosphorus. In the case of Pretty Boy TSS attenuation, the effect of a reservoir downstream, the Lock Raven reservoir (not shown) also contributes to the high attenuation (low delivery) of TSS loads.

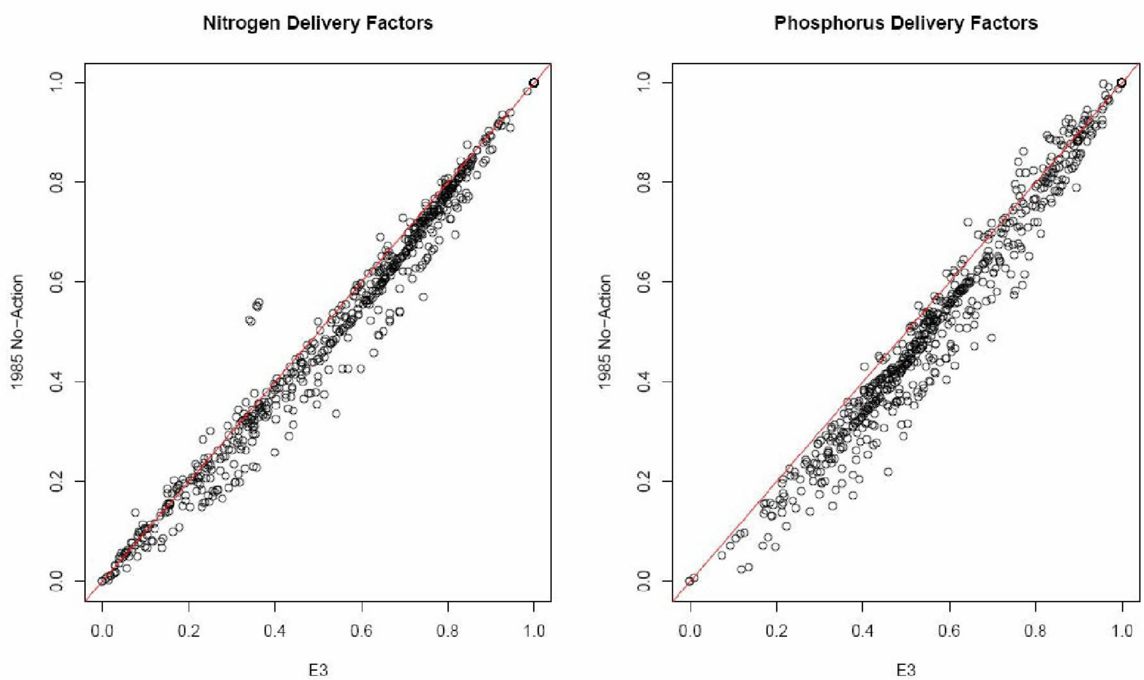


Figure 12-4. Nitrogen and phosphorus delivery factors from a high load 1985 No-Action Scenario compared to an E3 low load scenario.

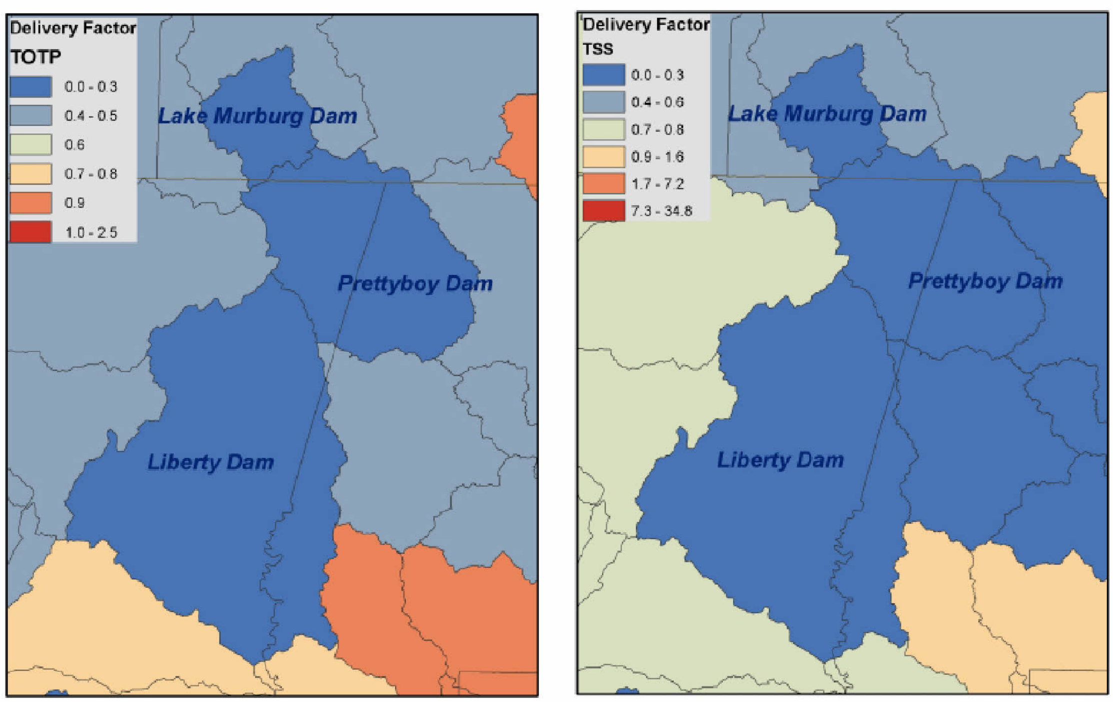


Figure 12-5. Phosphorus and TSS delivery factors for a series of reservoirs in Pennsylvania and Maryland.

12.4 Point Source Load Projections for Scenarios

The design flow is defined as the capacity of the wastewater treatment facility as designed and is used as the facility flow in some scenarios. Because design flow is usually greater than actual flow, and because the National Pollutant Discharge Elimination System permit limits on nutrients are constant, the point source loads in scenarios using point source design flows are higher than those using actual, as-measured flows. The TMDL Allocation Target Scenario and the Tributary Strategy Scenarios use design flows to estimate point source loads across the watershed.

The existing or current flow is the measured discharge in current years. Progress run scenarios and current flow-based scenarios, such as the 1985 and 2009 Scenarios, use current flows to calculate point source inputs. The nutrient and flow inputs for four key scenarios are described in Table 12-1.

Table 12-1. Point source load assumptions for the key scenarios of the Tributary Strategy, E3, 1985, No Action, and the 2010 No Action

Scoping Scenario Wastewater Input Deck Information

Scenario		Trib Strategy (TS)	E3	1985 No Action	2010 No Action
Definition		Latest state final or draft TS.	LOT Everywhere Tier 4 Level	Primary Treatment at the same level everywhere with 1985 flows	Primary Treatment at the same level everywhere with TS flows
Concentration	Sig Municipal Plants	Latest state final or draft TS. BOD=5 mg/l, DO=5 mg/l and TSS=5 mg/l	TN=3 and TP=0.1 BOD=3 mg/l, DO=6 mg/l and TSS=5 mg/l	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l
	Sig Industrial Plants	Latest state final or draft TS. BOD=5 mg/l, DO=5 mg/l and TSS=5 mg/l	TN=3 and TP=0.1 or TS level if less for industrial plants BOD=3 mg/l, DO=6 mg/l and TSS=5 mg/l	Highest Loads on record, or TS loads if greater BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l	Highest Loads on record, or TS loads if greater BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l
	Non-sig Plan	2006 data or newly submitted non sig data. BOD=30 mg/l, DO=4.5 mg/l and TSS=25 or 45 mg/l	TN=8 and TP=2 or TS level if less for industrial plants BOD =5 mg/l, DO=5 mg/l and TSS= 8 mg/l	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l
Flow		TS flows for sig plants 2006 data or newly submitted non sig data for non-sig plants	Same as TS scenario	1985 Flows	Same as TS scenario
DC CSO		Long Term Control Plan full Implementation	Long Term Control Plan full Implementation	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l current base condition flow	TN=25 mg/l and TP =6 mg/l BOD=200 mg/l, DO=4.5 mg/l and TSS=45 mg/l current base condition flow
Refinement from Phase 4.3 Scenarios		adding non-sig data and BOD, DO and TSS Defaults	adding non-sig data and BOD, DO and TSS Defaults	New Scenario	New Scenario

Note: Scenarios of TS and E3 adopted the same definitions as the related scenarios previously approved by the workgroup and run on the phase 4 model. Some refinements have been made into these scenarios as listed in the table. The 1985 No Action and 2010 No Action scenarios are new ones. E3 and 2010 No Action use the flows from the TS scenario, in which most significant facilities use design flows. Please note that there was about 35% excess wastewater treatment capacity in total in 2006 based on the actuall flow data reported from 588 facilities in 2006. By current growth rate, there should still be a significant portion of excess capacity left by 2010. Therefore, the overall wastewater flows used in TS, E3 and 2010 No Action would be significantly greater than what should be by 2010. But for comparison purpose, we will not redefine the flows for these three scenarios and keep using what the TS defined. The excess capacities by 2010 could be considered as the reserved capacities under the facility loading caps.

12.5 Key Scenarios

Several key scenarios illustrate features of model behavior under high and low loadings (Figures 12-6 to 12.8). The highest loading is the historically high loads of 1985. Before 1985, the nutrient loads are estimated to have steadily increased, particularly since the widespread use of fertilizers and hydrocarbon fuels occurred after the mid-1940s. After 1985, the reductions by state and federal actions began to reduce nutrient loads from the 1985 zenith. The lowest loads are represented by the All Forest Scenario. Notable is the similarity of the Tributary Strategy based on the 2003 Allocation and the current 2010 TMDL Target Allocation. The sediment loads of the 2010 TMDL Target Allocation have an allowable range of 6,066 million pounds to 6,671 million pounds because of the use of an explicit margin of safety for sediment in the TMDL as

described in Section 6 of the TMDL documentation:
http://www.regulations.gov/#!documentDetail;D=EPA-R03-OW-2010-0736-0024

Figures 12-9, 12-10, and 12-11 display estimated pollutant loadings from the main sources simulated in the Phase 5.3 Watershed Model. The 2010 TMDL Target Allocations are not shown here by source because the 2010 Watershed Implementation Plans (WIPs) were still being developed at the time of publication (http://www.regulations.gov/#!documentDetail;D=EPA-R03-OW-2010-0736-0025). Only Figure 12-9 has on-site wastewater treatment system (OWTS), or septic system loads, because nitrogen is the only nutrient exported from this source in the Phase 5.3 simulation. Tables 12-2, 12-3, and 12-4 have estimated delivered TN, TP, and total suspended solids (TSS) loads respectively by state-basin for the 1985 Scenario, 2009 Scenario, 2010 No Action Scenario, Tributary Strategy Scenario, and the 2010 E3 Scenario.

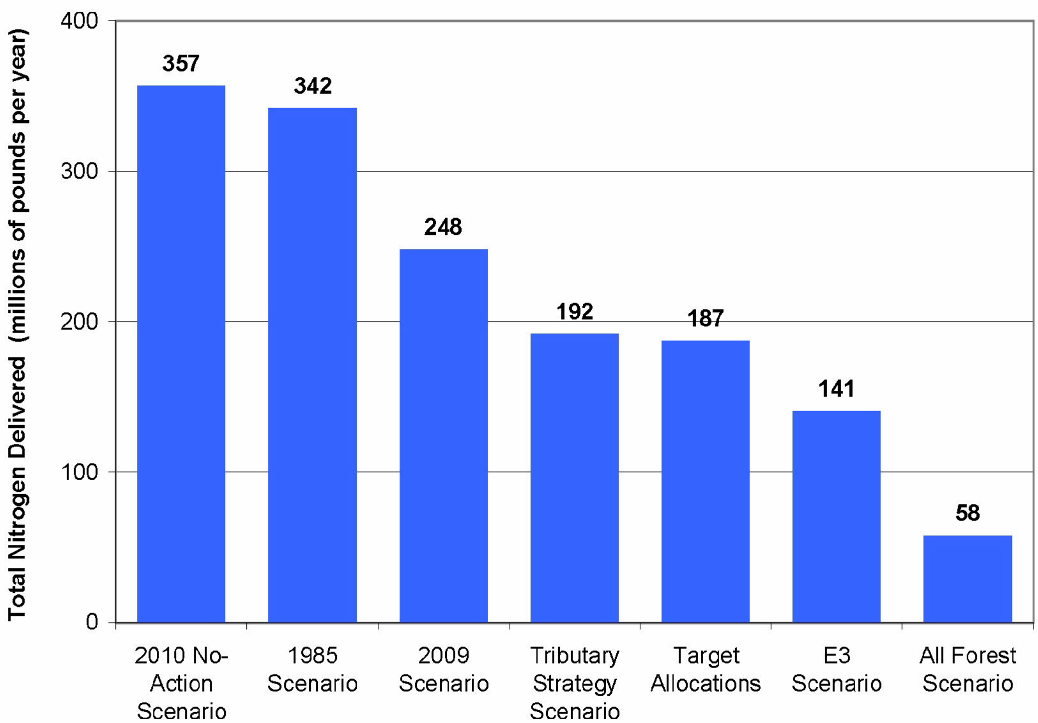


Figure 12-6. Total nitrogen loads delivered to the Bay for the key scenarios (million pounds per year).

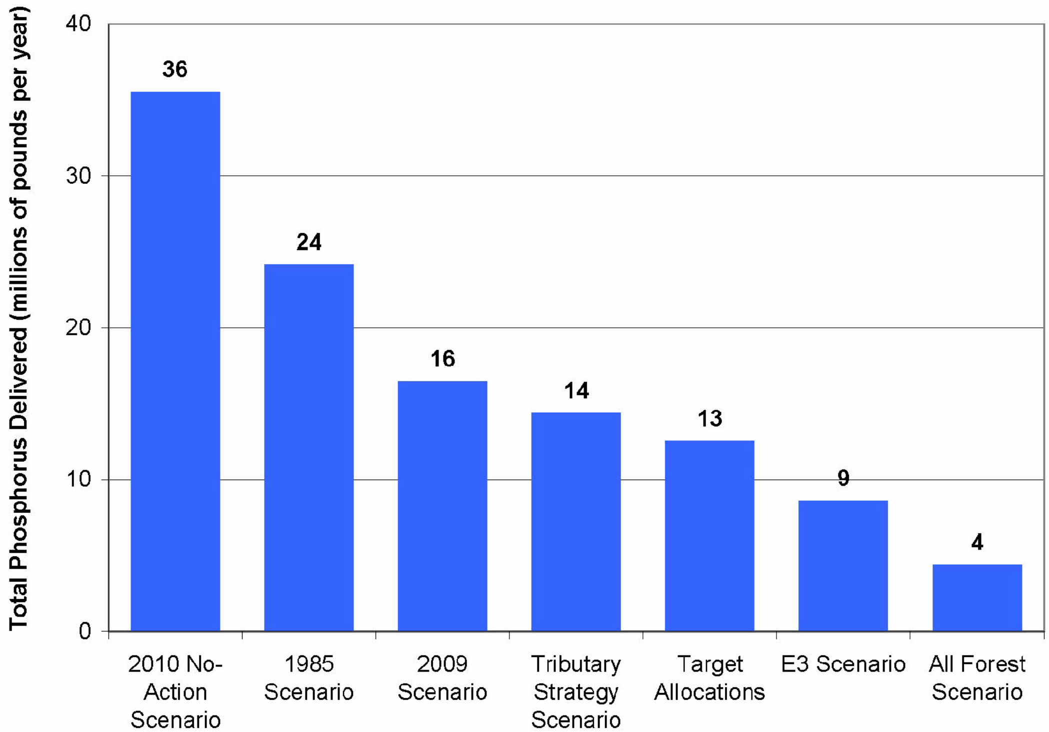
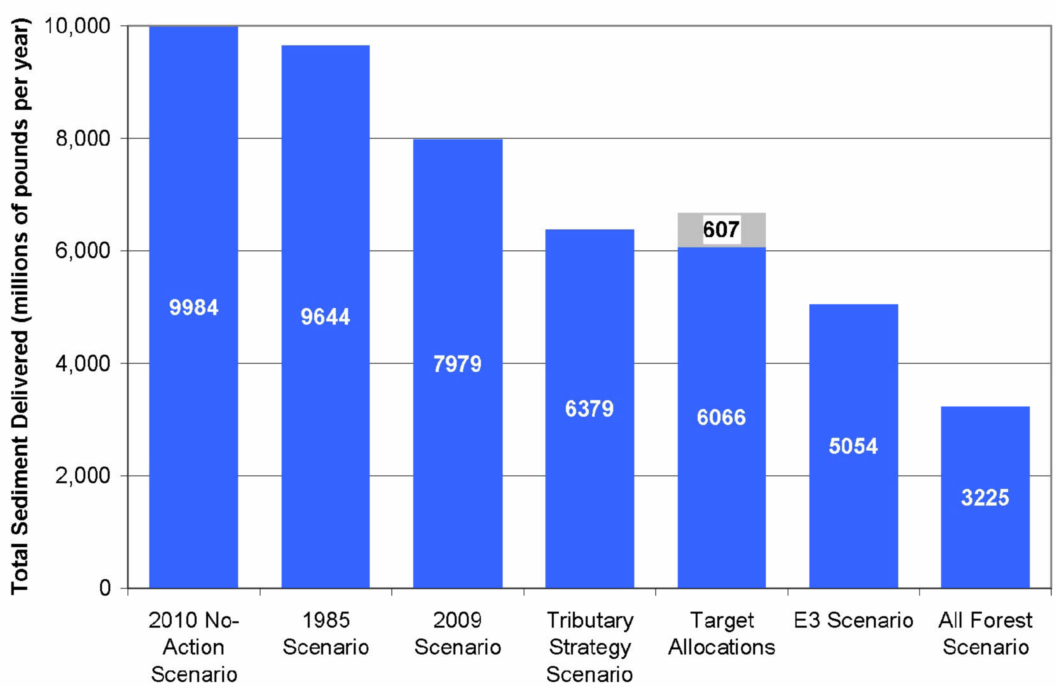


Figure 12-7. Total phosphorus loads delivered to the Bay for the key scenarios (million pounds per year).



Note: The Target Allocations has a range of sediment loads representing an explicit TMDL margin of safety for sediment loads.

Figure 12-8. Total sediment loads delivered to the Bay for the key scenarios (million pounds per year).

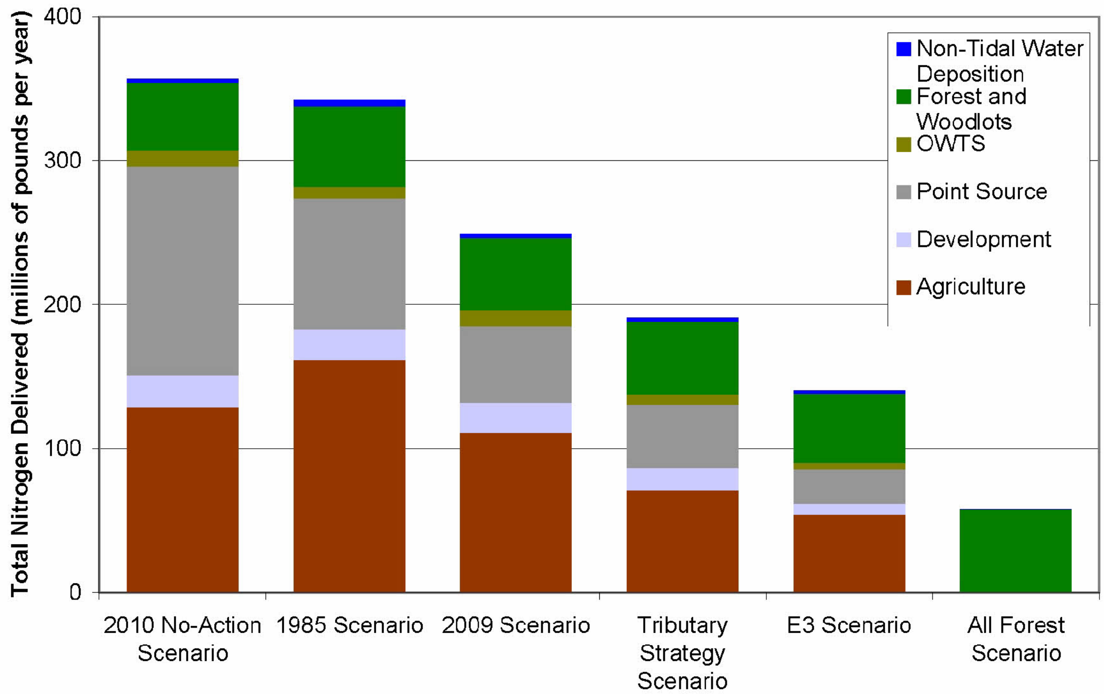


Figure 12-9. Total nitrogen loads delivered to the Bay by source (million pounds per year).

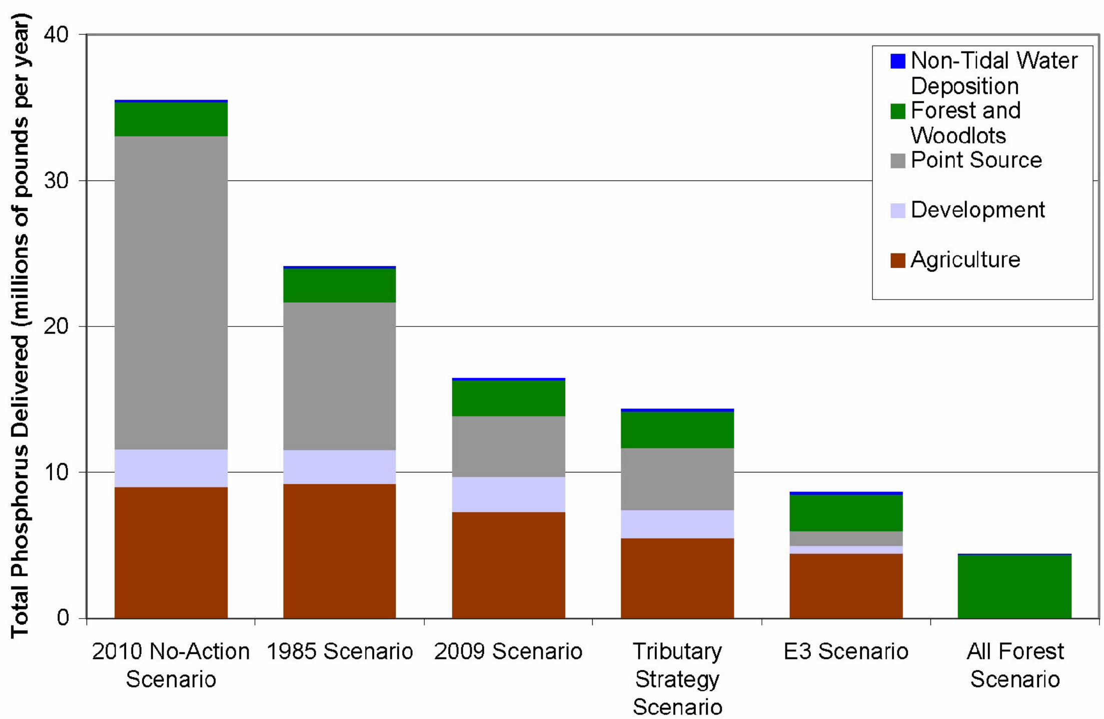


Figure 12-10. Total phosphorus loads delivered to the Bay by source (million pounds per year).

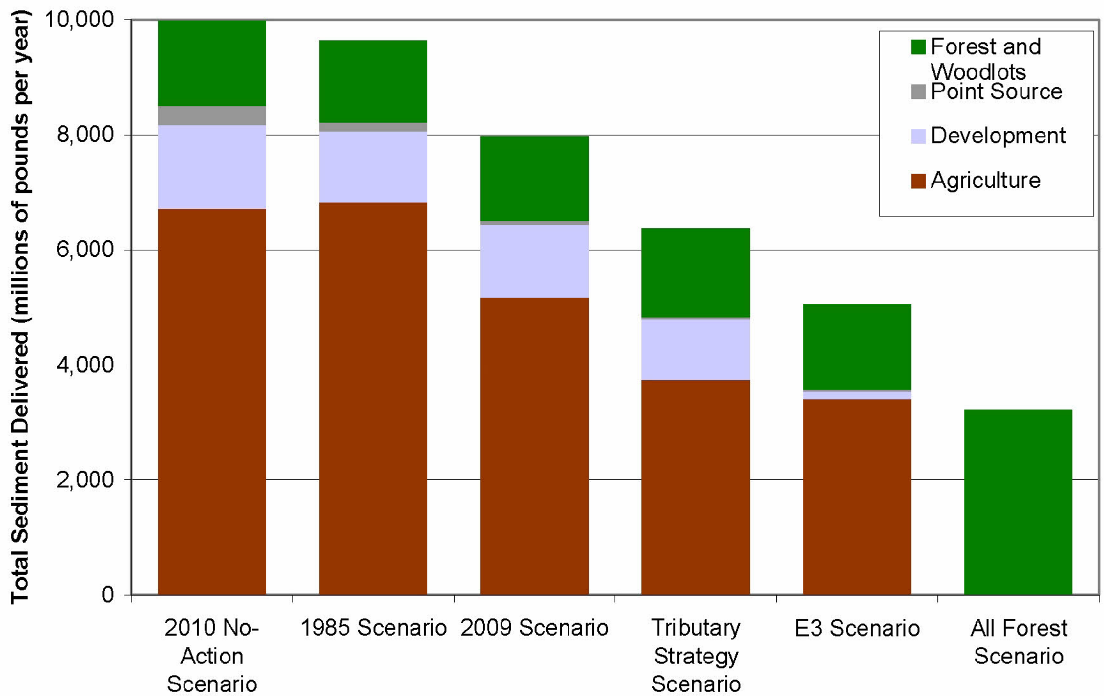


Figure 12-11. Total sediment loads delivered to the Bay by source (million pounds per year).

12.5.1 1985 High Historical Load Scenario

This scenario uses the estimated 1985 land uses, animal numbers, atmospheric deposition, and the point source loads described in Table 12.4.1. This scenario's nutrient load estimates (Figures 12-12, 12-13, and 12-14), along with the 2010 No Action Scenario (Tables 12-2, 12-3, and 12-4), have the highest delivered loads of nutrients and sediment to the Bay (using a constant 1991–2000 hydrology).

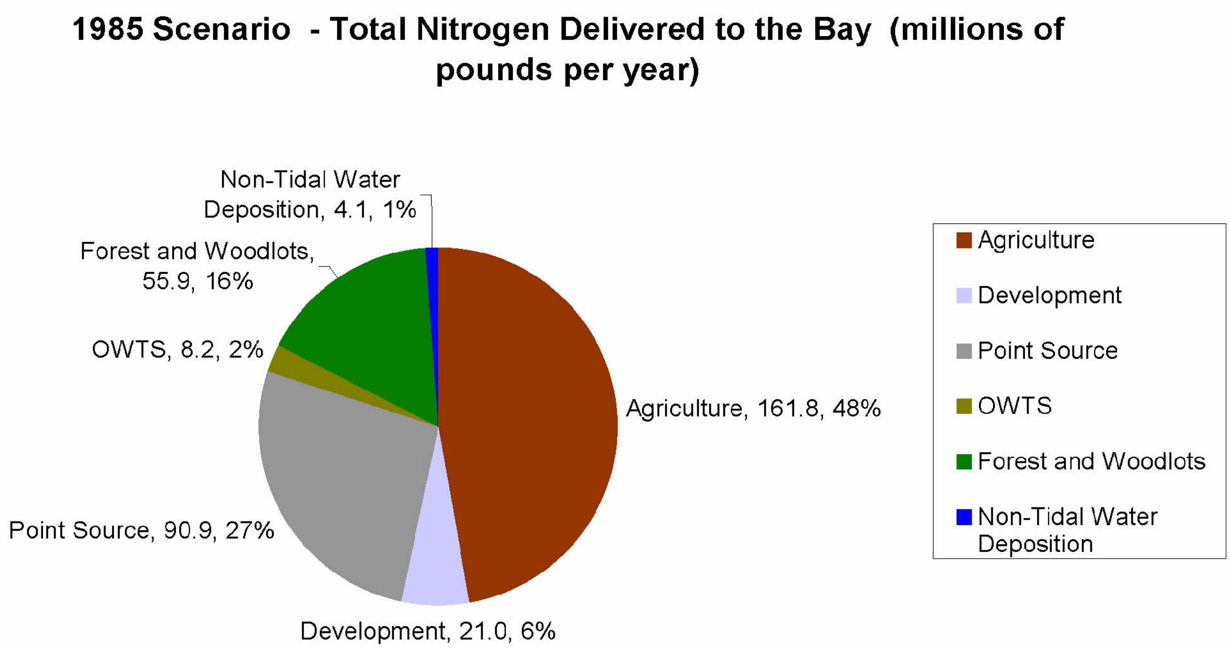


Figure 12-12. Nitrogen loads delivered to the Bay by source for the 1985 Scenario (units of million pounds per year followed by percent of total load).

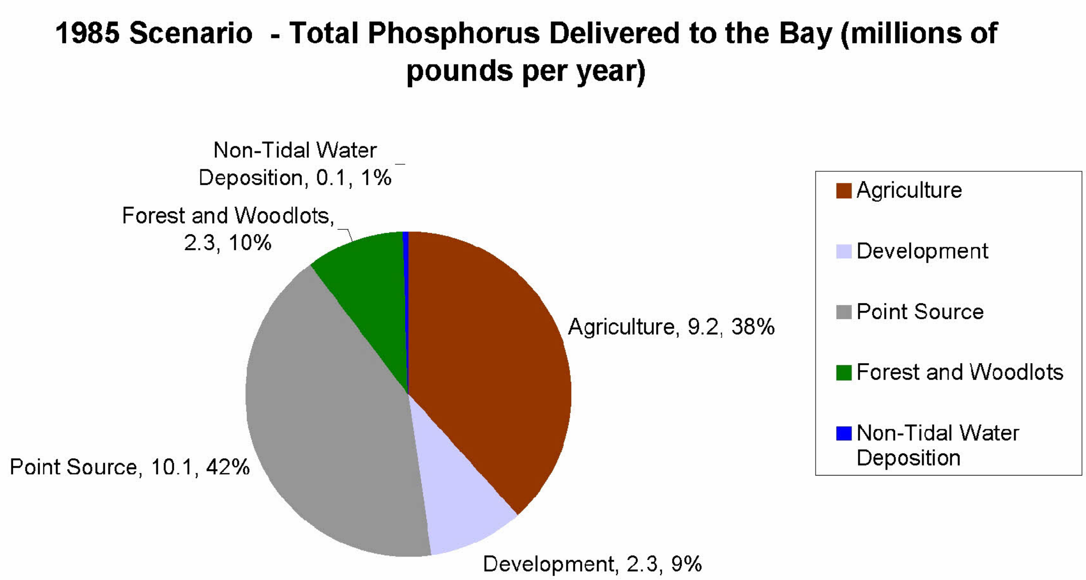


Figure 12-13. Phosphorus loads delivered to the Bay by source for the 1985 Scenario (units of million pounds per year followed by percent of total load).

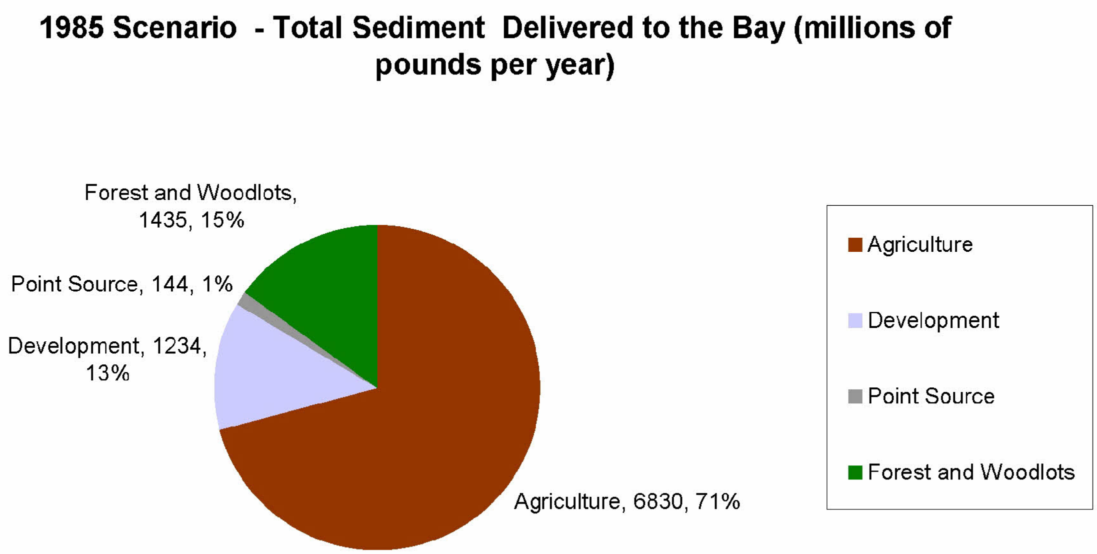


Figure 12-14. Sediment loads delivered to the Bay by source for the 1985 Scenario (units of million pounds per year followed by percent of total load).

12.5.2 2009 Scenario

This scenario uses the estimated 2009 land uses, animal numbers, atmospheric deposition, and point source loads (Table 12-1). The 2009 year was chosen for simulation as it was the most recent year full input information was available for the 2010 TMDL assessment (Tables 12-2, 12-3, and 12-4). Figures 12-15 through 12-17 show the relative proportion of delivered loads for the 2009 Scenario. Note that as loads decrease in point sources, developed, and development forest loads increase as a relative proportion compared to the 1985 condition.

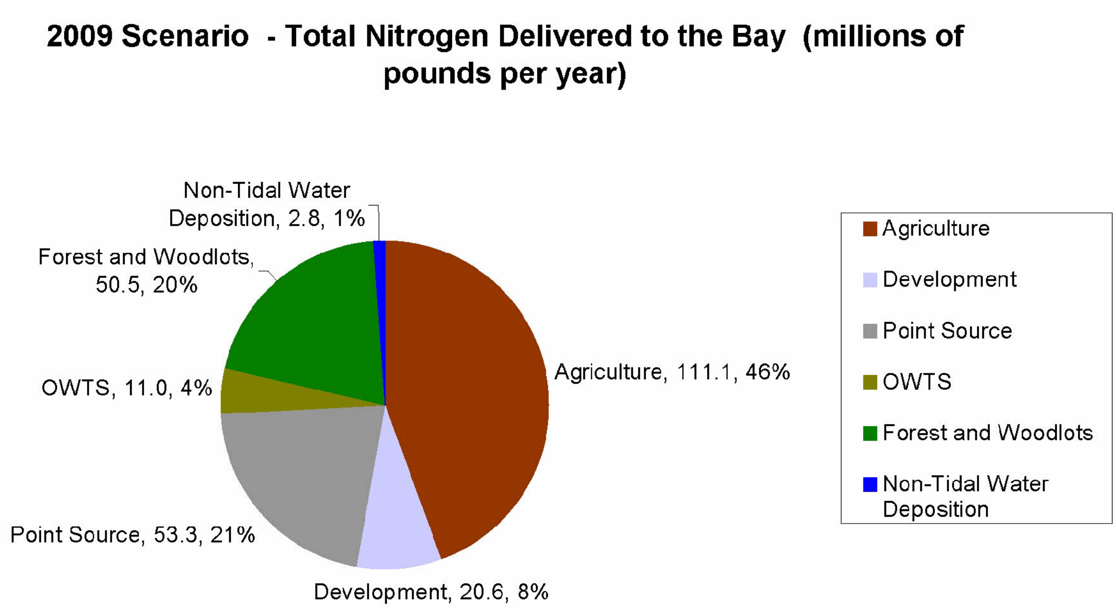


Figure 12-15. Nitrogen loads delivered to the Bay by source for the 2009 Scenario (units of million pounds per year followed by percent of total load).

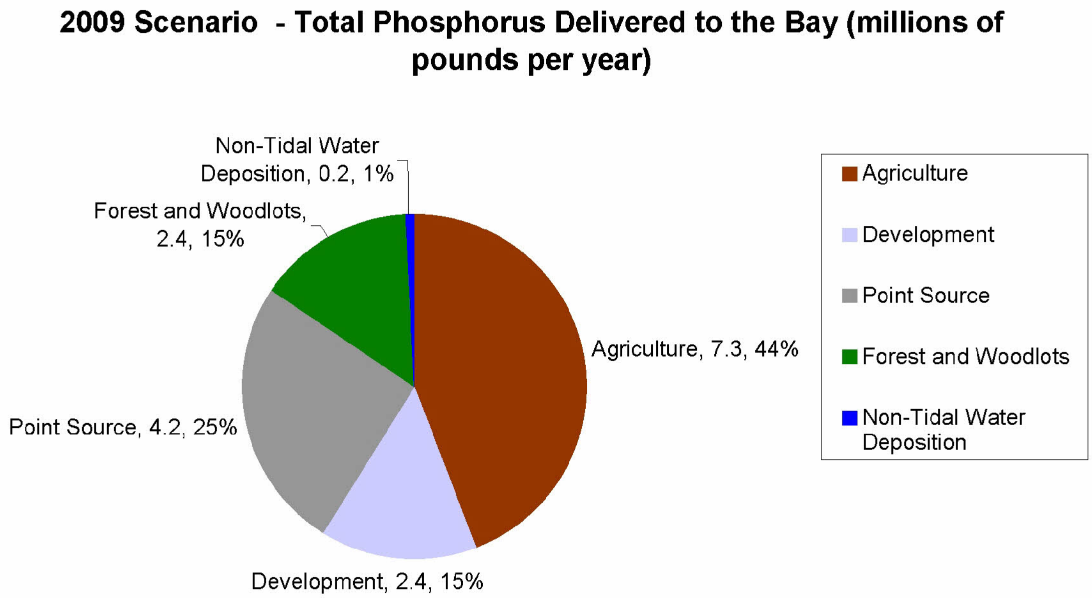


Figure 12-16 Phosphorus loads delivered to the Bay by source for the 2009 Scenario (units of million pounds per year followed by percent of total load).

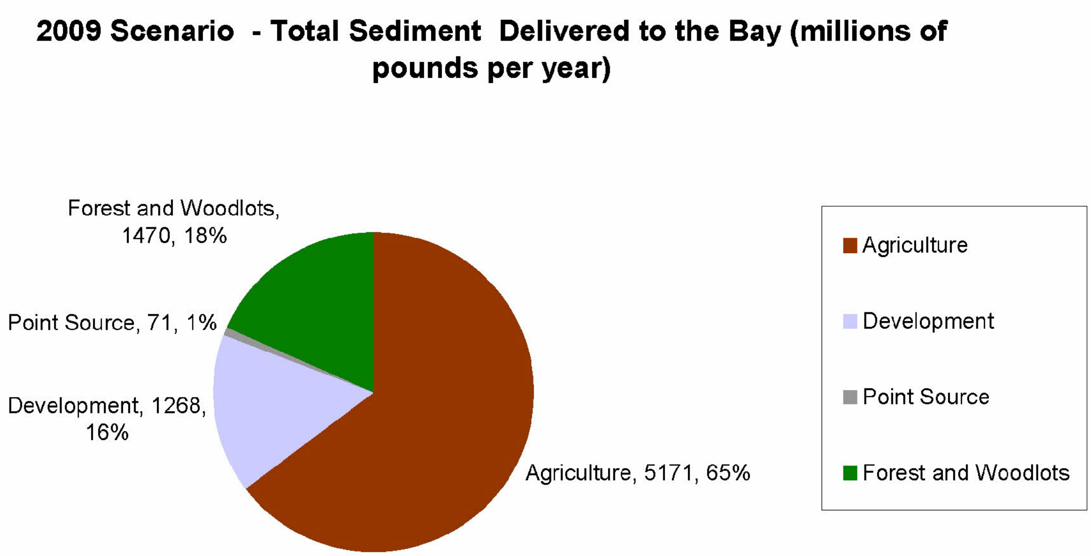


Figure 12-17. Sediment loads delivered to the Bay by source for the 2009 Scenario (units of million pounds per year followed by percent of total load).

12.5.3 2010 Tributary Strategy Scenario

This scenario estimates the nutrient and sediment loads of the jurisdictions' 2003 Tributary Strategies throughout the Chesapeake Bay watershed (Tables 12-2, 12-3, and 12-4). This scenario included an accounting for all the Tributary Strategy BMPs on a 2010 land use, and the 2010 estimated permitted loads for all the significant and nonsignificant wastewater dischargers, as described in Table 12-1, that the watershed states have developed to achieve the states' Bay dissolved oxygen and chlorophyll water quality standards. Any adjustments needed to the states' Tributary Strategies to reflect changes in state laws or policies (e.g., permitting of significant wastewater discharge facilities) since agreement on the 2003 Allocations and development of the initial set of jurisdictional tributary strategies were also included in this scenario's input decks. Atmospheric deposition inputs were from the CMAQ 12-km grid with an estimated 2010 deposition and included estimated State Implementation Plans (SIPs) to reach the 2010 Air Quality Standards (as described in Section 5).

Figures 12-18 through 12-20 show the relative proportion of delivered loads for the 2010 Tributary Strategy Scenario.

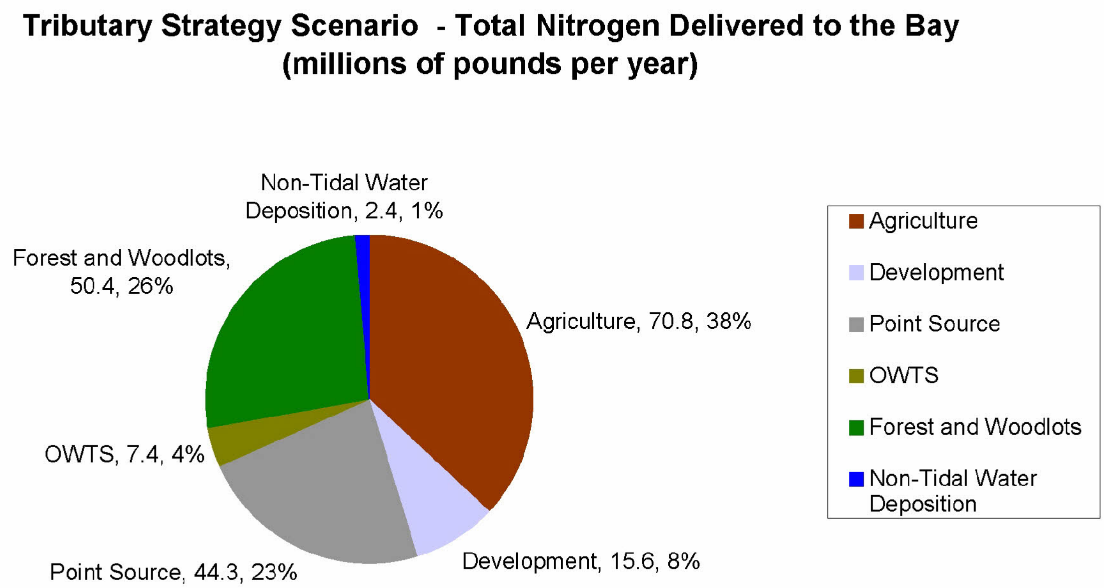


Figure 12-18. Nitrogen loads delivered to the Bay by source for the Tributary Strategy Scenario (units of million pounds per year followed by percent of total load).

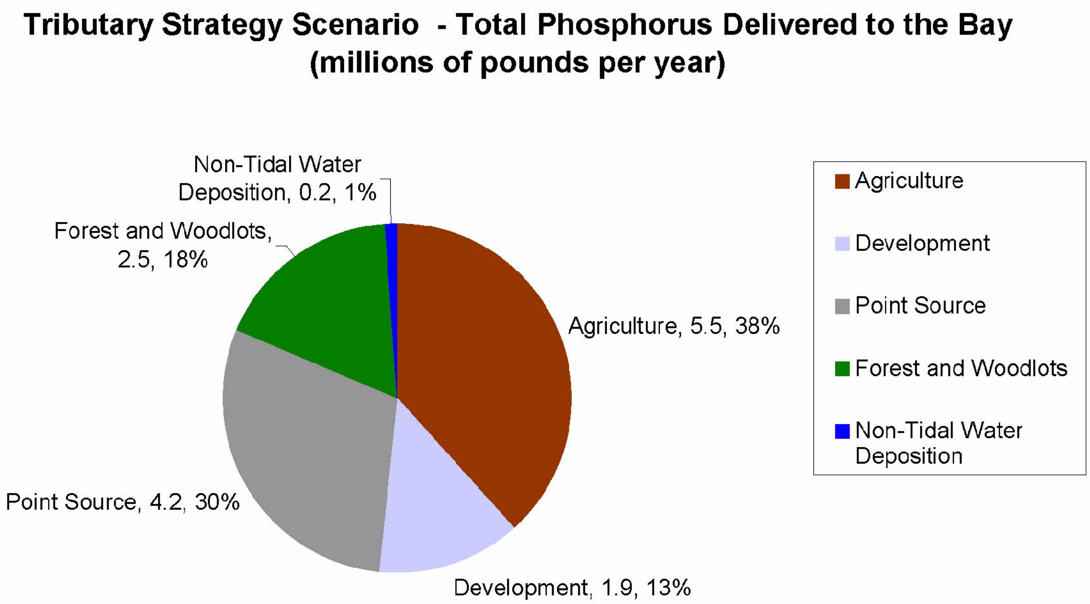


Figure 12-19. Phosphorus loads delivered to the Bay by source for the Tributary Strategy Scenario (units of million pounds per year followed by percent of total load).

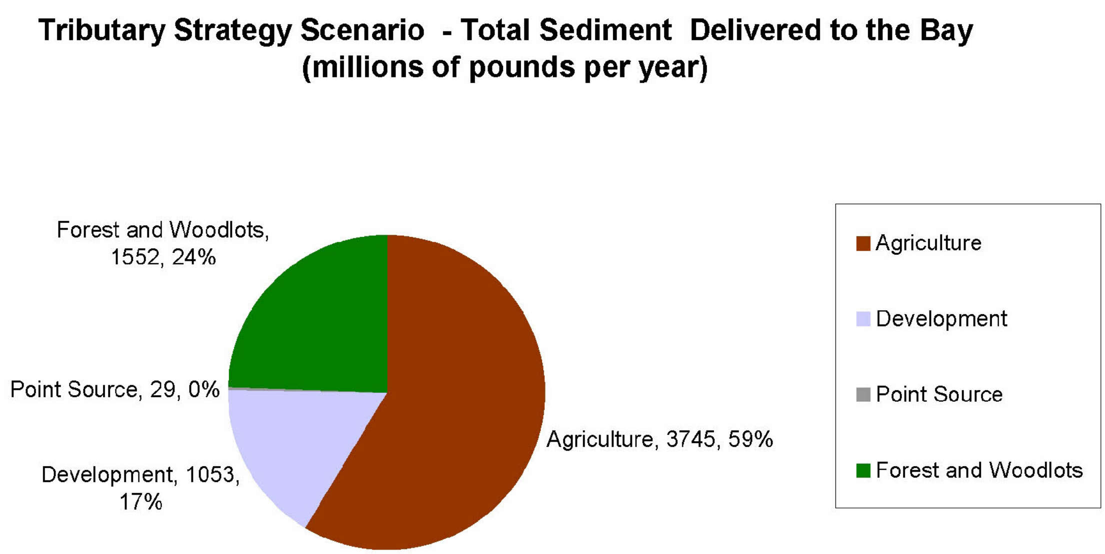


Figure 12-20. Sediment loads delivered to the Bay by source for the Tributary Strategy Scenario (units of million pounds per year followed by percent of total load).

12.5.4 1985 No-Action Scenario

The No-Action scenario is a *what-if* scenario of watershed conditions without, or with minimal, managed controls on load sources. Specifically, this scenario estimates nutrient and sediment loads under the conditions of no environmental point sources and nonpoint source controls applied to a 1985 land use and population (Figures 12-21, 12-22, and 12-23). All management actions including major widespread management practices such as nutrient management and conservation tillage were eliminated in this scenario. Point source load assumptions were of primary treatment only with no phosphate detergent ban in place (Table 12-1).

12.5.4.1 1985 No-Action Point Sources

- **No-Action Significant municipal wastewater treatment facilities**
  - Flow = Tributary Strategy flows where most are at design flows
  - Nitrogen effluent concentration = 18 mg TN/l
  - Phosphorus effluent concentration = 6 mg TP/l
  - BOD = 30 milligrams per liter (mg/l), DO = 4.5 mg/l and TSS = 15 mg/l
- **No-Action Significant industrial dischargers**
  - Flow = Tributary Strategy flows where most are at design flows
  - Highest Loads on record or Tributary Strategy loads if greater
  - BOD = 30 mg/l, DO = 4.5 mg/l and TSS = 15 mg/l
- **No-Action Nonsignificant municipal wastewater treatment facilities**
  - Flow = Tributary Strategy flows
  - Nitrogen effluent concentration = 18 mg TN/l
  - Phosphorus effluent concentration = 6 mg TP/l
  - BOD = 30 mg/l, DO = 4.5 mg/l and TSS = 15 mg/l

12.5.4.2 1985 No-Action Combined Sewer Overflows

- Flow = current base condition flow
- Nitrogen effluent concentration = 18 mg TN/l
- Phosphorus effluent concentration = 6 mg TP/l
- BOD = 200 mg/l, DO = 4.5 mg/l and TSS = 45 mg/l

12.5.4.3 1985 No-Action Septic Practices

- There are no nutrient and sediment control practices and programs in the No-Action scenario throughout the Chesapeake Bay watershed for on-site waste treatment.

12.5.4.4 1985 No-Action Atmospheric Deposition

- The 2020 CMAQ Scenario is used for atmospheric deposition in both the E3 and No-Action scenarios in determining the *controllable* load. The approach allows for the agreed-to TMDL air reductions to be already considered in the nitrogen load reductions needed to achieve the water quality standards and the remainder of the load reductions to be achieved by the WIPs are alone tracked in the nitrogen allocations to the Bay states

12.5.4.5 1985 No-Action Urban Practices

- There are no nutrient and sediment control practices and programs in the No-Action scenario throughout the Chesapeake Bay watershed for the urban sector.

12.5.4.6 1985 No-Action Agricultural Practices

- There are no nutrient and sediment control practices and programs in the No-Action scenario throughout the Chesapeake Bay watershed for OWTS (septic).

12.5.4.7 1985 No-Action Forestry Practices

- There are no nutrient and sediment control practices and programs in the No-Action scenario throughout the Chesapeake Bay watershed on forest lands where there could be environmental effects from timber harvesting and dirt and gravel roads.

1985 No-Action Scenario - Total Nitrogen Delivered to the Bay (millions of pounds per year)

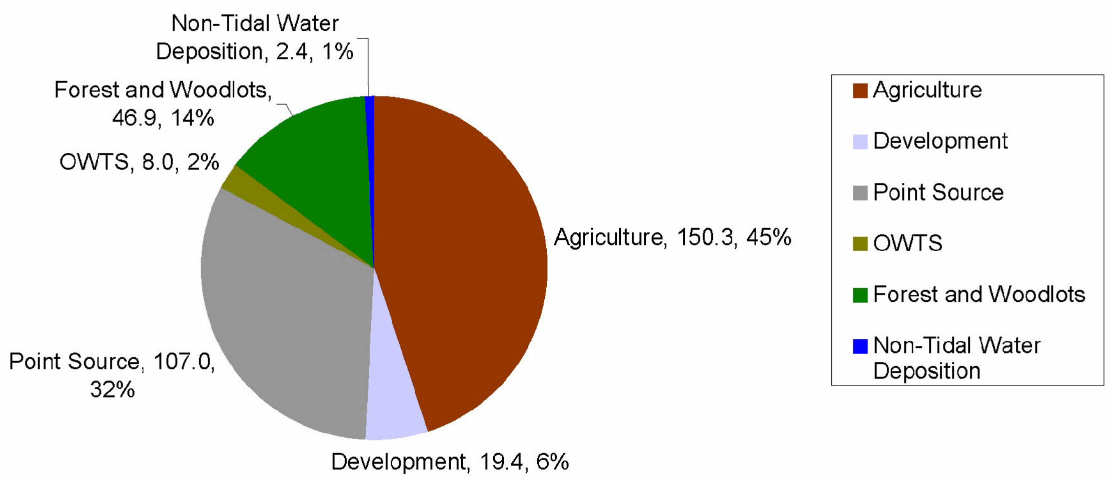


Figure 12-21. Nitrogen loads delivered to the Bay by source for the 1985 No-Action Scenario (units of million pounds per year followed by percent of total load).

1985 No-Action Scenario - Total Phosphorus Delivered to the Bay (millions of pounds per year)

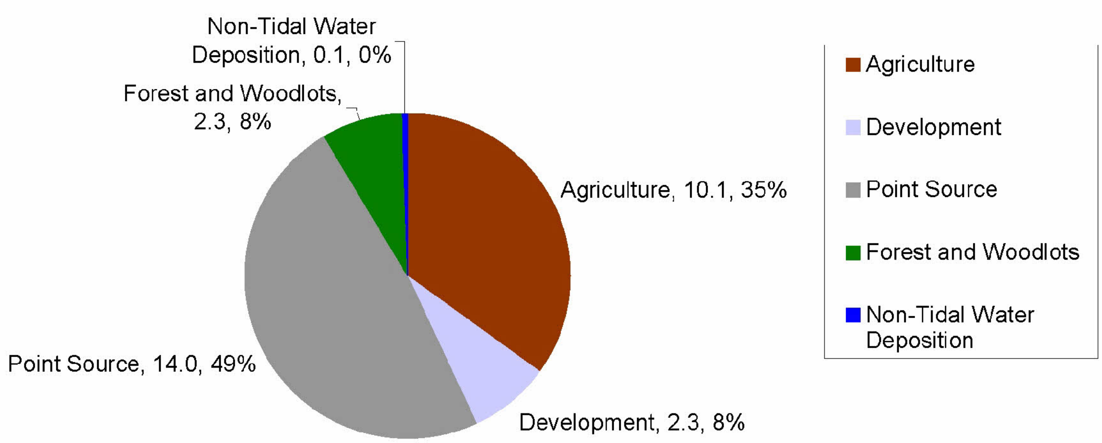


Figure 12-22. Phosphorus loads delivered to the Bay by source for the 1985 No-Action Scenario (units of million pounds per year followed by percent of total load).

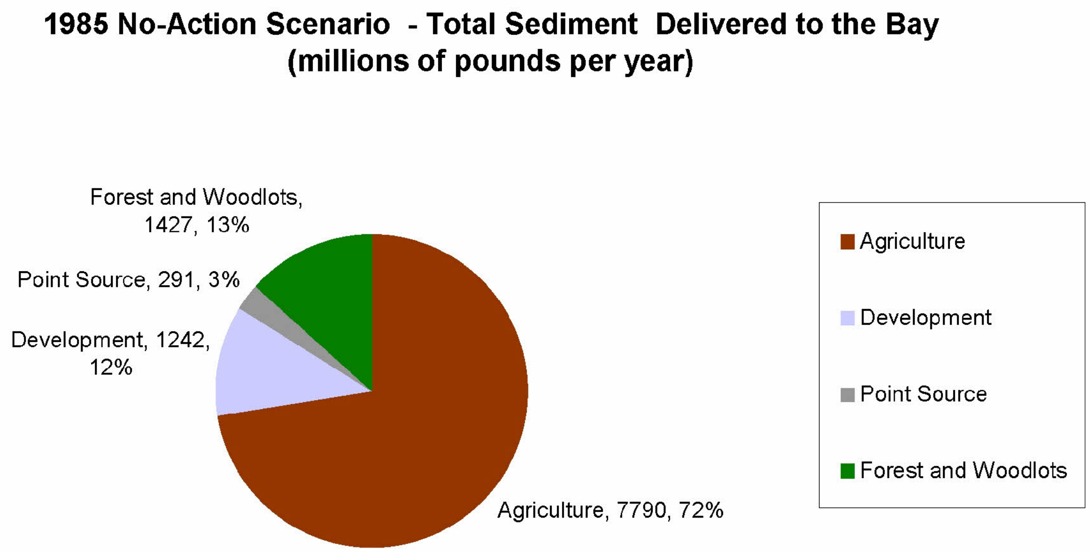


Figure 12-23. Sediment loads delivered to the Bay by source for the 1985 No-Action Scenario (units of million pounds per year followed by percent of total load).

12.5.5 2010 No-Action Scenario

This scenario estimates nutrient and sediment loads under the conditions of no environmental point sources and nonpoint source controls using a 2010 land use and population (Tables 12-2, 12-3, and 12-4). Major widespread management practices such as nutrient management and conservation tillage were eliminated in this scenario. Point source load assumptions were of primary treatment only with no phosphate detergent ban (Table 12-1). Figures 12-24, 12-25, and 12-26 show the relative proportion of nutrient and sediment delivered loads for the 2010 No-Action Scenario. Development of inputs for the 2010 No-Action Scenario are the same as in the 1985 No-Action Scenario except that the 2010 land uses and populations were used.

The No-Action scenario is a *what-if* scenario of watershed conditions without or with minimal managed controls on load sources. It is used with the E3 scenario to define *controllable* loads, the difference between No-Action and E3 loads. Controllable loads is a component of the methodology used to develop 2010 TMDL target loads needed to meet water quality standards.

The No-Action condition is often the starting point for developing tributary strategies and implementation plans. All past practices, programs and treatment upgrades that exist are credited toward the needed reductions from the No-Action *baseline*.

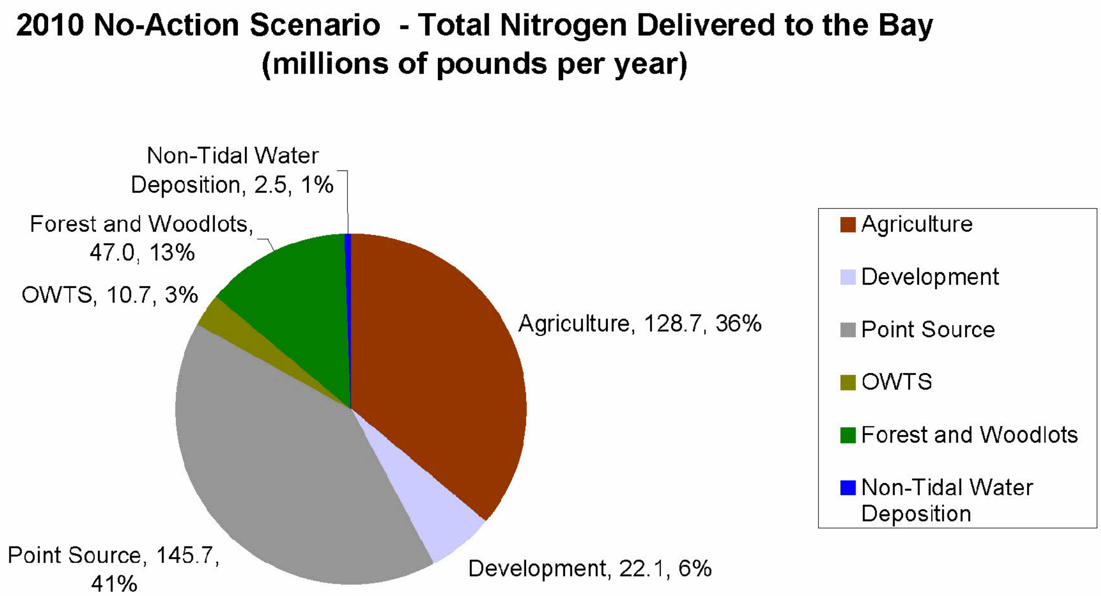


Figure 12-24. Nitrogen loads delivered to the Bay by source for the 2010 No-Action Scenario (units of million pounds per year followed by percent of total load).

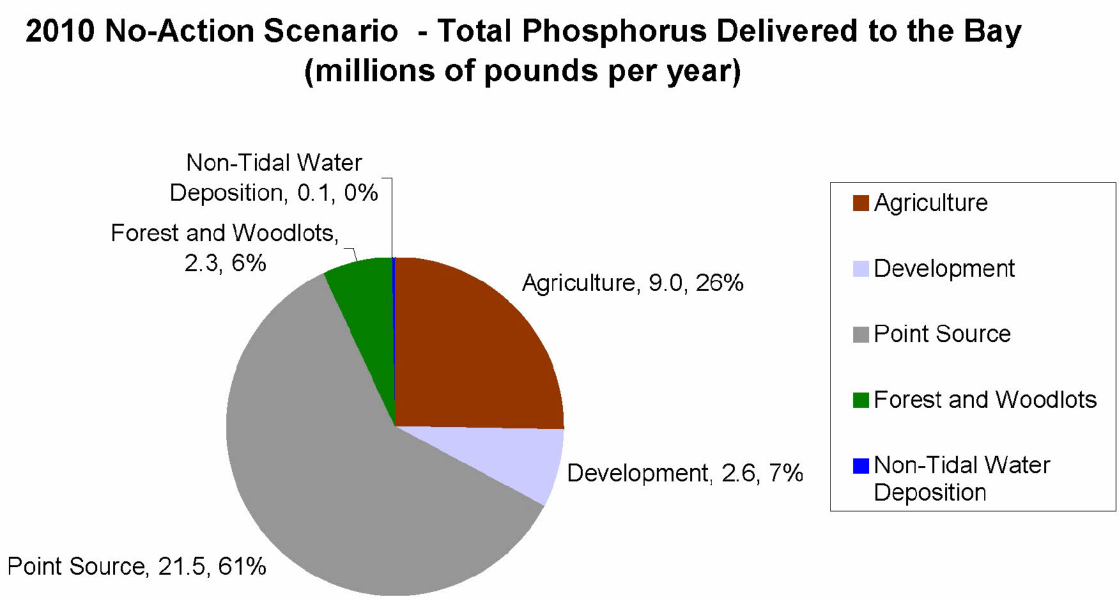


Figure 12-25. Phosphorus loads delivered to the Bay by source for the 2010 No-Action Scenario (units of million pounds per year followed by percent of total load).

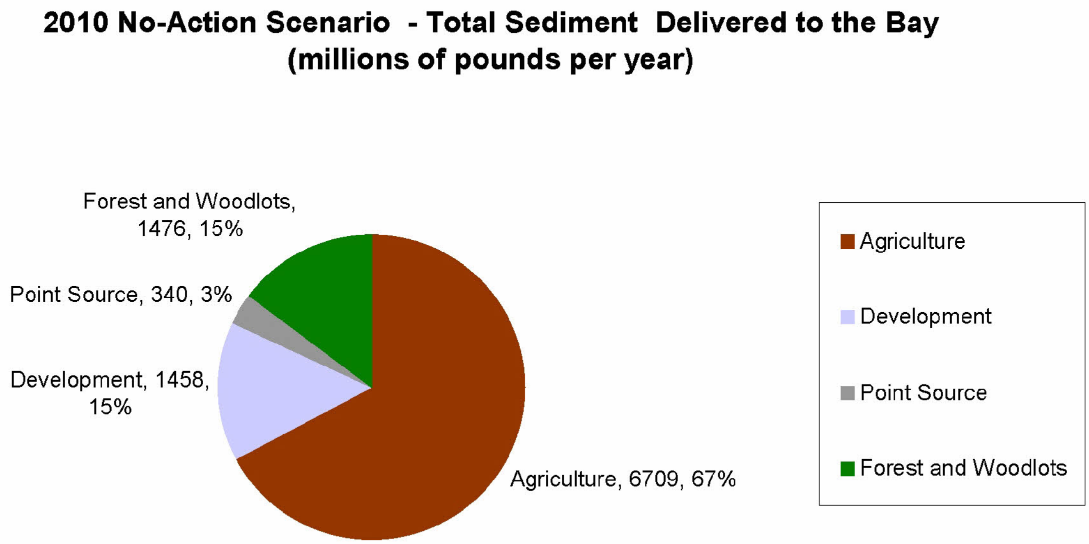


Figure 12-26. Sediment loads delivered to the Bay by source for the 2010 No-Action Scenario (units of million pounds per year followed by percent of total load).

12.5.6 Everyone, Everything, Everywhere (E3) Scenario

The E3 Scenario is an estimate of applying management actions to the fullest possible extent. The E3 scenario is a what-if scenario of watershed conditions with theoretical maximum levels of managed controls on load sources (Tables 12-2, 12-3, and 12-4). There are no cost and few physical limitations to implementing BMPs for point and nonpoint sources in E3. It is used with the No-Action scenario to define controllable loads, the difference between No-Action and E3 loads.

Controllable loads are a component of the methodology to allocate target loads needed to meet water quality standards to different regions of the Chesapeake Bay watershed. Load allocations of target caps also take into consideration the relative effects on water quality standards from load reductions in regions throughout the watershed. Differences between No-Action and E3 scenario loads provide equity among regions of the Chesapeake Bay watershed in that assumptions of point source controls and nonpoint source practice and program implementation levels for each scenario are spatially universal. Differences among regions occur because of more *inherent* differences in, for example, animal and human populations, the number and types of point source facilities, agricultural land types and areas, urban land areas, atmospheric deposition, and so on.

Generally, E3 implementation levels and their associated reductions in nutrients and sediment could not be achieved for many practices, programs and control technologies when considering physical limitations and participation levels. E3 includes most technologies, practices and programs that have been reported by jurisdictions as part of annual model assessments, Tributary Strategies, and Milestones.

For most nonpoint source BMPs, it was assumed that the load from every available acre of the relevant land area was being controlled by a suite of existing or innovative practices. In addition, management programs converted land uses from those with high yielding nutrient and sediment loads to those with lower. E3 does not include the entire suite of practices because of the goal of achieving maximum load reductions. The BMPs that are fully implemented have been estimated to produce greater reductions than alternative practices that could be applied to the same land base.

The current definition of E3 includes a greater number of types of practices than historic E3 scenarios developed in 2003 or in limit of technology scenarios developed in even earlier phases of the watershed model. That is because of wider development and application of new management technologies over the past two decades, which have increased the scope of options of nutrient and sediment management practices. In the future, E3 load reductions are expected to expand through greater effectiveness of practices and greater efforts on operation and maintenance. For point sources, nutrient control technologies are assumed to apply to all dischargers. Figures 12-27, 12-28, and 12-29 show the relative proportion of delivered loads for the E3 Scenario.

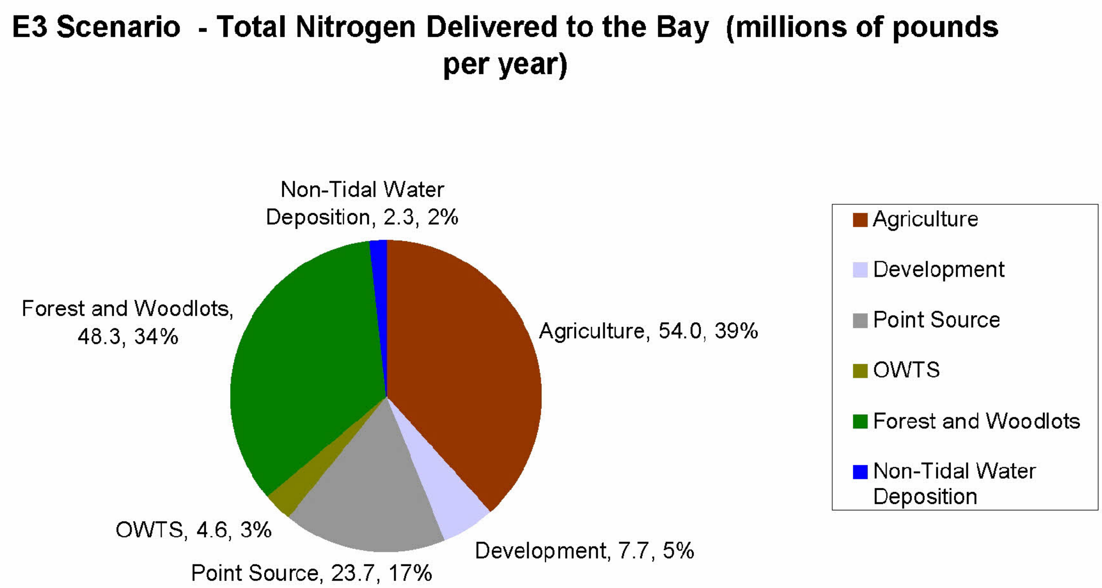


Figure 12-27. Nitrogen loads delivered to the Bay by source for the E3 Scenario (units of million pounds per year followed by percent of total load).

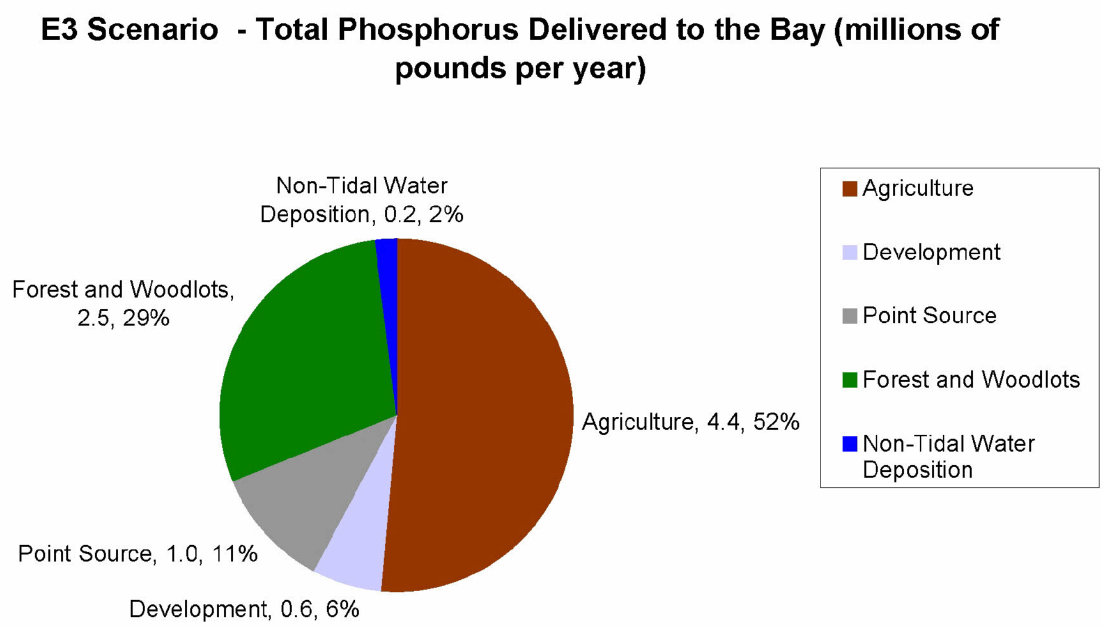


Figure 12-28. Phosphorus loads delivered to the Bay by source for the E3 Scenario (units of million pounds per year followed by percent of total load).

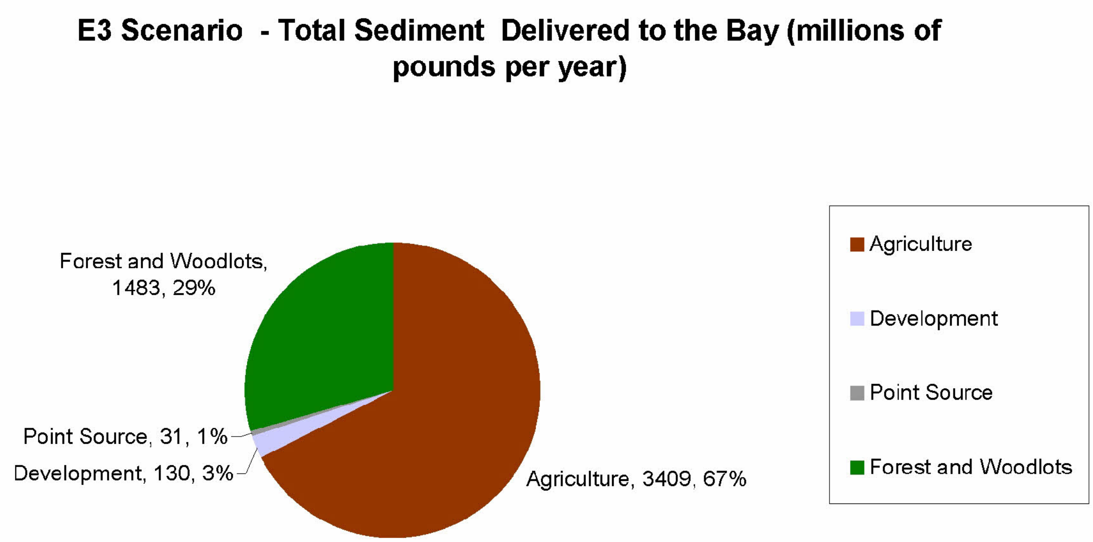


Figure 12-29. Sediment loads delivered to the Bay by source for the E3 Scenario (units of million pounds per year followed by percent of total load).

12.5.6.1 E3 Point Sources

- E3 Significant municipal wastewater treatment facilities
  - Flow = Tributary Strategy flows where most are at design flows
  - Nitrogen effluent concentration = 3 mg TN/l
  - Phosphorus effluent concentration = 0.1 mg TP/l

- BOD = 3 mg/l, DO = 6 mg/l and TSS = 5 mg/l

- E3 Significant industrial dischargers
  - Flow = Tributary Strategy flows where most are at design flows
  - Nitrogen effluent concentration = 3 mg TN/l or Tributary Strategy concentration if less
  - Phosphorus effluent concentration = 0.1 mg TP/l or Tributary Strategy concentration if less
  - BOD = 3 mg/l, DO = 6 mg/l and TSS = 5 mg/l
- E3 Nonsignificant municipal wastewater treatment facilities
  - Flow = Design or 2006 flow if design is not available
  - Nitrogen effluent concentration = 8 mg TN/l or Tributary Strategy concentration if less
  - Phosphorus effluent concentration = 2 mg TP/l or Tributary Strategy concentration if less
  - BOD = 5 mg/l, DO = 5 mg/l and TSS = 8 mg/l
- E3 Nonsignificant industrial wastewater treatment facilities
  - Applies the percentage of equivalent reduction from No-Action (18 mg/l TN, 3 mg/l TP) to E3 (3 mg/l TN, 0.1 mg/l TP) to the 2010 load estimates

12.5.6.2 E3 Combined Sewer Overflows

- 100 percent overflow reduction through storage and treatment, separation or other practices. Storage and treatment is assumed in current model scenarios

12.5.6.3 E3 Septic Practices

- E3 Septic connections
  - 10 percent of septic systems connected to wastewater treatment facilities
- E3 Septic denitrification and maintenance
  - Remaining septic systems after connections employ denitrification technologies and are maintained through regular pumping to achieve a 55 percent TN load reduction at the edge-of-septic-field
  - Septic systems are maintained by a responsible management entity or in perpetuity through a maintenance contract

12.5.6.4 E3 Atmospheric Deposition

- E3 atmospheric deposition uses the Bay Program’s air scenario that shows the maximum reductions in deposition—a projection to 2020 called the Maximum Feasible Scenario
- The Water Quality Goal Implementation Team decided to use the same atmospheric deposition for both the E3 and No-Action scenarios in the allocation methodology
- The 2020 scenario represents incremental improvements and control options (beyond 2020 CAIR) that might be available to states for application by 2020 to meet a more stringent ozone standard, stricter than 0.08 ppm—such as the proposed 0.070 ppm ozone standard of January 2010
- Emissions projections for the 2020 E3 scenario assume the following:
  - National/regional and available State Implementation Plans (SIPs) for NOx reductions—with lower ozone season nested emission caps in OTC states; targeting use of maximum controls for coal fired power plants in or near nonattainment areas
  - Electric Generating Units (EGUs):

        - CAIR second phase in place, in coordination with earlier NOx SIP call
        - NOx Budget Trading Program (NBP)
        - Regional Haze Rule and guidelines for Best Available retrofit Technology (BART) for reducing regional haze
        - Clean Air Mercury Rule (CAMR) in place
    - Non-EGU point sources:
        - New supplemental controls, such as low NOx burners, plus increased control measure efficiencies on planned controls and step up of controls to maximum efficiency measures, e.g., replacing SNCRs (Selective Non-Catalytic Reduction) with SCRs (Selective Catalytic Reduction) control technology
        - Solid Waste Rules—Hospital/Medical Waste Incinerator Regulations
    - On-Road mobile sources:
        - On-Road Light Duty Mobile Sources—Tier 2 vehicle emissions standards and the Gasoline Sulfur Program, which affects SUVs, pickups, and vans, which are subject to same national emission standards as cars
        - On-Road Heavy Duty Diesel Rule—Tier 4: New emission standards on diesel engines starting with the 2010 model year for NOx, plus increased penetration of diesel retrofits and continuous inspection and maintenance using remote onboard diagnostic systems
    - Clean Air Non-Road Diesel Rule:
        - Off-road diesel engine vehicle rule, reduced NOx emissions from marine vessels in coastal shipping lanes, and locomotive diesels (phased in by 2014) require controls on new engines
        - Off-road large spark ignition engine rules affect recreational vehicles (marine and land based)
    - Area (nonpoint area) sources: switching to natural gas and low sulfur fuel
- E3 Agricultural Ammonia Emissions Reductions
    - Assumes rapid incorporation of fertilizers in soils at the time of application, litter treatment, biofilters on housing ventilation systems, and covers on animal waste storage or treatment facilities
    - The overall benefit of reduced emissions from confined animal housing and waste storage as well as lower emissions from fertilized soils is a 15 percent reduction of ammonia deposition

12.5.6.5 E3 Urban Practices

- E3 Forest conservation and urban growth reduction
    - All projected loss of forest from development is retained or planted in forest
- E3 Riparian forest buffers on urban
    - 10 percent of pervious riparian areas without natural vegetation (forests and wetlands) associated with urban lands are buffered as forest for each modeled hydrologic segment in the Chesapeake Bay watershed
    - The area of un-buffered riparian land is determined using the best available data (1) 1:24K National Hydrography Dataset, and (2) 2001 land cover
- E3 Tree planting on urban
    - Forest conservation and urban riparian forest buffers account for tree plantings in the urban sector

- E3 Stormwater Management
    - Regions with karst topography (low permeability) and Coastal Plain Lowlands (high groundwater)
        - 50 percent of area—impervious cover reduction
        - 30 percent of area—filtering practices designed to reduce TN by 40 percent, TP by 60 percent, and SED by 80 percent from a pre-BMP condition
        - 20 percent of area—infiltration practices designed to reduce TN by 85 percent, TP by 85 percent, and SED by 95 percent from a pre-BMP condition
    - Ultra-urban regions—defined as high- and medium-intensity land cover
        - 50 percent of area—impervious cover reductions, e.g., cisterns and collections systems to capture rainwater for reuse
        - 30 percent of area—filtering practices, e.g., sand filters, bio-retention, dry wells
        - 20 percent of area—infiltration practices, e.g., infiltration trenches and basins
    - Other urban/suburban regions
        - 10 percent of area—impervious cover reduction
        - 30 percent of area—filtering practices, e.g., sand filters, bioretention
        - 60 percent of area—infiltration practices
- E3 Erosion and sediment controls
    - Controls of the runoff from all bare-construction land use areas are assumed to be at a level so that the construction loads are equal to the nutrient and sediment edge-of-stream loads from pervious urban under E3 conditions
- E3 Nutrient management on urban
    - All pervious urban acres are under nutrient management
- E3 Controls on extractive (active and abandoned mines)
    - Controls of the runoff from all extractive land use areas are assumed to be to a degree so that the loads are equal to the nutrient and sediment edge-of-stream loads from pervious urban under E3 conditions

12.5.6.6 E3 Agricultural Practices

- E3 Conservation tillage
    - All row crops are conservation-tilled
- E3 Enhanced nutrient management applications
    - All cropland is under enhanced nutrient management—the hybrid of reduced application rate and decision agriculture
    - Long-term, adaptive management approach with continuous improvement
- E3 Riparian forest buffers on agriculture
    - Riparian areas without natural vegetation (forests and wetlands) associated with agricultural lands are buffered as forest
    - That equates to 15 percent of cropland and 10 percent of pasture land including the pasture stream corridor for each modeled hydrologic segment in the Chesapeake Bay watershed
    - The area of un-buffered riparian land is determined using the best available data (1) 1:24K National Hydrography Dataset, and (2) 2001 land cover
    - Current implementation of riparian grass buffers is considered converted to riparian forest buffers

- E3 Wetland restoration
  - 5 percent of available agricultural acres in crops and grazed for each modeled hydrologic segment in the Chesapeake Bay watershed
- E3 Carbon sequestration/alternative crops
  - 5 percent of the available row crop acres for each modeled hydrologic segment in the Chesapeake Bay watershed
  - Program is replacement of row crops with long-term grasses that serve as a carbon bank
- E3 Agricultural land retirement
  - Retirement of highly erodible land is considered in the E3 practices of riparian forest buffers, wetland restoration, and carbon sequestration practices, which typically have equal or greater environmental benefits
- E3 Tree planting on agriculture
  - Tree planting is considered in the E3 practice of riparian forest buffers, which typically have equal or greater environmental benefits
- E3 Conservation plans (non-nutrient management)
  - Conservation plans are fully implemented on all agricultural land (row crops, hay, alfalfa, and pasture)
- E3 Cover crops and commodity cover crops
  - Early-planting rye cover crops with drilled seeding on all relevant row crops
    - The watershed-wide average of 81 percent of row crops is not associated with small-grain production is applied to each modeled hydrologic segment in the Chesapeake Bay watershed
  - Early-planting wheat commodity cover crops with drilled seeding on remaining row crops (associated with small-grain production)
    - The watershed-wide average of 19 percent of row crops associated with small-grain production is applied to each modeled hydrologic segment in the Chesapeake Bay watershed
- E3 Pasture Management
  - Stream Access Control with Fencing—Exclusion fencing is assumed to protect the stream corridor area designated as the degraded land use and the area between the stream bank and fence is converted to (and is part of) the agricultural forest buffer determination
  - Prescribed grazing—All upland pasture area is assumed to be under prescribed grazing
  - Dairy Precision Feeding and Forage Management (also listed under E3 Dairy Precision Feeding)—All dairy heifers have reduced nutrient concentrations in excreted manure of TN = 24 percent and TP = 28 percent from a pre-feed management condition
    - Management approaches can include increased productivity and use of on-farm grass forage
  - Horse pasture management benefits are the same as those for fencing and prescribed grazing practices for livestock in general
- E3 Animal waste management/runoff control
  - Controls of runoff of manure nutrients from the production area of animal feeding operations is assumed to be at a level such that loads are equal to the nutrient and sediment edge-of-stream loads associated with hay that does not receive fertilizer applications
  - Other practices typically associated with animal waste management and runoff control, that could affect runoff from the production area, are addressed separately in the E3

scenario. Those include Poultry and Swine Phytase, Dairy Precision Feeding, Manure Transport, and Ammonia Emissions Reductions.

- E3 Poultry phytase
  - The phosphorus content in the manure of all poultry is reduced by 32 percent from a pre-feed management condition
- E3 Swine phytase
  - The phosphorus content in excreted manure of all swine is reduced from a pre-feed management condition by 17 percent
- E3 Dairy precision feeding
  - All dairy heifers have reduced nutrient concentrations in excreted manure of TN = 24 percent and TP = 28 percent from a pre-feed management condition
- E3 Ammonia emissions reductions
  - Also under E3 Atmospheric Deposition—Agricultural Ammonia Emissions Reductions
  - Assumes rapid incorporation of fertilizers in soils at the time of application, litter treatment, biofilters on housing ventilation systems, and covers on animal waste storage or treatment facilities
  - The overall benefit of reduced emissions from confined animal housing and waste storage as well as lower emissions from fertilized soils is a 15 percent reduction of ammonia deposition
- E3 Nursery Management
  - All nursery operations are managed through a number of practices to protect water quality including properly addressing nutrient management and incorporating erosion and sedimentation controls
  - Controls are to a degree so that runoff from nursery areas is equal to the nutrient and sediment edge-of-stream loads from hay that does not receive fertilizer applications

12.5.6.7 E3 Forest Harvest Practices

- E3 Forest harvesting practices
  - Controls of runoff from the disturbed area of timber harvest operations are assumed to be at a level such that the nutrient and sediment loads are equal to edge-of-stream loads associated with the forest/woody land use
  - It is assumed that the BMPs, designed to minimize the environmental effects from timber harvesting (such as road building and cutting/thinning operations), are properly installed on all harvested lands with no measurable increase in nutrient and sediment discharge

12.5.7 All Forest with Current Air Scenario

This scenario uses an all forest land use and current estimated atmospheric deposition loads for the 1991–2000 period and represents estimated loads with maximum reductions on the land including the elimination of fertilizer, point source, and manure loads. However, this scenario has loads greater than a pristine scenario, which would have reduced input atmospheric deposition loads by about an order of magnitude.

12.5.8 Base Calibration Scenario

The Base Calibration Scenario is used in data correction procedures and represents the calibration of the time series of land uses, loads and hydrology over the 10-year simulation period of 1991–2000 used for TMDL scenarios.

12.5.9 Draft Allocation Scenario

The Draft Allocation Scenario was first developed with the appropriate levels of effort between 2010 No Action and E3 scenarios for each of the state-basins (Table 12-5). This initial scenario will be ultimately replaced by Phase I WIPs for each state-basin. The Phase I WIPs, finalized at the end of December 2010 will ultimately determine the final allocation load in each state basin, but finalization of the WIPs will occur after this document's publication. The Allocation Scenario represented here is only the starting point of the process toward a final 2010 TMDL Allocation, yet it is broadly representative of the relative magnitude of the 2010 Allocation.

Table 12-2. Delivered total nitrogen loads (million lbs/year) by state basin and scenario

		1985 Scenario	2009 Scenario	2010 No-Action	Tributary Strategy	2010 E3 Scenario
Eastern Shore (EAS)						
	DE	4,588,529	4,147,086	4,981,254	3,162,504	2,222,548
	MD	16,568,146	12,415,609	17,695,385	9,918,230	7,175,859
	PA	574,816	441,687	489,057	310,563	196,879
	VA	2,146,674	1,904,887	2,409,616	1,044,100	793,313
James Basin (JAM)						
	VA	42,584,946	30,412,356	49,107,779	27,589,016	16,448,647
	WV	23,412	23,854	17,101	19,458	18,176
Potomac Basin (POT)						
	DC	6,212,283	2,855,381	9,779,192	2,259,955	1,468,851
	MD	29,570,734	18,770,321	32,956,674	16,212,194	11,419,374
	PA	7,248,044	6,228,235	6,691,046	4,279,902	3,500,393
	VA	30,154,276	20,218,162	33,526,560	16,492,511	13,312,959
	WV	8,086,649	5,909,347	6,374,392	4,837,689	3,609,325
Rappahannock Basin (RAP)						
	VA	8,915,254	6,984,028	9,329,515	5,645,991	4,389,007
Susquehanna Basin (SUS)						
	MD	2,289,950	1,544,260	1,749,924	1,274,129	872,303
	NY	16,767,064	10,947,653	11,029,769	9,658,103	6,385,689
	PA	127,310,101	101,652,996	119,293,002	71,768,524	56,888,598
Western Shore (WES)						
	MD	26,999,660	13,996,079	36,643,184	9,868,767	5,990,445
	PA	40,664	30,135	37,579	14,119	8,619
Patuxent Basin PAT)						
	MD	4,160,979	3,088,204	6,007,886	2,784,225	2,034,656
York Basin (YOR)						
	VA	7,601,483	6,362,320	8,486,752	5,117,871	3,831,906
Totals (million lbs/year)						
State	DC	6.2	2.9	9.8	2.3	1.5
	DE	4.6	4.1	5.0	3.2	2.2
	MD	79.6	49.8	95.1	40.1	27.5

	NY	16.8	10.9	11.0	9.7	6.4
	PA	135.2	108.4	126.5	76.4	60.6
	VA	91.4	65.9	102.9	55.9	38.8
	WV	8.1	5.9	6.4	4.9	3.6
Basin	EAS	23.9	18.9	25.6	14.4	10.4
	JAM	42.6	30.4	49.1	27.6	16.5
	POT	81.3	54.0	89.3	44.1	33.3
	RAP	8.9	7.0	9.3	5.6	4.4
	SUS	146.4	114.1	132.1	82.7	64.1
	WES	27.0	14.0	36.7	9.9	6.0
	PAT	4.2	3.1	6.0	2.8	2.0
	YOR	7.6	6.4	8.5	5.1	3.8
Chesapeake Bay Total (million lbs/year)						
		342	248	357	192	141

Table 12-3. Delivered total phosphorus loads (million lbs/year) by state basin and scenario

		1985 Scenario	2009 Scenario	2010 No-Action	Tributary Strategy	2010 E3 Scenario
Eastern Shore (EAS)						
	DE	370,641	315,358	446,444	271,162	187,123
	MD	1,704,256	1,171,280	2,001,694	1,039,837	826,806
	PA	21,566	19,495	21,552	13,042	10,512
	VA	264,400	193,312	295,896	130,265	123,177
James Basin (JAM)						
	VA	6,492,248	3,304,019	7,521,929	3,282,591	1,545,503
	WV	13,735	13,917	11,839	10,020	7,750
Potomac Basin (POT)						
	DC	101,791	86,378	1,580,879	105,387	52,123
	MD	1,486,278	1,012,709	3,564,086	1,032,903	630,712
	PA	571,534	537,617	614,869	380,015	327,222
	VA	2,195,669	1,958,685	4,965,897	1,699,459	981,541
	WV	852,623	819,300	915,409	543,561	367,617
Rappahannock Basin (RAP)						
	VA	1,295,724	1,083,857	1,651,858	937,860	598,837
Susquehanna Basin (SUS)						
	MD	89,722	61,633	73,429	56,923	39,778
	NY	1,067,774	801,589	971,152	649,947	433,369
	PA	4,480,707	3,409,157	5,250,245	2,655,145	1,762,855
Western Shore (WES)						
	MD	1,621,215	768,302	3,632,564	676,099	253,145
	PA	1,305	1,062	1,372	683	712
Patuxent Basin (PAT)						
	MD	479,917	291,157	825,724	294,082	130,031
York Basin (YOR)						
	VA	1,026,570	624,858	1,162,280	593,360	346,334
Totals (million lbs/year)						
State	DC	0.1	0.1	1.6	0.1	0.1
	DE	0.4	0.3	0.4	0.3	0.2
	MD	5.4	3.3	10.1	3.1	1.9
	NY	1.1	0.8	1.0	0.6	0.4
	PA	5.1	4.0	5.9	3.0	2.1
	VA	11.3	7.2	15.6	6.6	3.6
	WV	0.9	0.8	0.9	0.6	0.4
Basin	EAS	2.4	1.7	2.8	1.5	1.1
	JAM	6.5	3.3	7.5	3.3	1.6
	POT	5.2	4.4	11.6	3.8	2.4
	RAP	1.3	1.1	1.7	0.9	0.6
	SUS	5.6	4.3	6.3	3.4	2.2
	WES	1.6	0.8	3.6	0.7	0.3
	PAT	0.5	0.3	0.8	0.3	0.1
	YOR	1.0	0.6	1.2	0.6	0.3
Chesapeake Bay Total (million lbs/year)						
		24	16	36	14	9

Table 12-4. Delivered total sediment loads (tons/year) by state basin and scenario

		1985 Scenario	2009 Scenario	2010 No-Action	Tributary Strategy	2010 E3 Scenario
Eastern Shore (EAS)						
	DE	37,798	32,265	46,647	27,281	15,493
	MD	130,624	92,749	147,256	78,424	62,927
	PA	19,561	15,802	20,216	9,993	9,753
	VA	11,078	8,213	10,993	5,165	4,415
James Basin (JAM)						
	VA	769,356	618,375	743,150	497,986	342,850
	WV	14,478	14,137	14,115	9,017	7,262
Potomac Basin (POT)						
	DC	11,286	15,906	49,994	5,146	2,059
	MD	465,191	388,161	512,809	331,108	234,639
	PA	160,452	153,596	193,052	111,952	112,204
	VA	643,712	542,498	663,622	409,896	302,227
	WV	211,455	173,414	206,152	114,036	82,641
Rappahannock Basin (RAP)						
	VA	442,833	376,088	424,112	343,374	316,823
Susquehanna Basin (SUS)						
	MD	52,974	36,480	50,123	31,546	26,771
	NY	191,317	163,587	165,929	150,679	103,793
	PA	1,304,816	1,112,924	1,404,642	855,868	779,598
Western Shore (WES)						
	MD	155,411	118,825	161,555	102,261	52,355
	PA	442	363	531	235	268
Patuxent Basin (PAT)						
	MD	94,468	57,010	78,816	51,354	30,231
York Basin (YOR)						
	VA	104,529	70,846	98,381	55,622	40,837
Totals (tons/year)						
State	DC	11,286.1	15,905.5	49,993.6	5,145.8	2,058.5
	DE	37,798.4	32,264.7	46,647.1	27,280.8	15,493.5
	MD	898,668.2	693,224.6	950,558.9	594,693.2	406,921.9
	NY	191,317.1	163,587.3	165,928.7	150,678.7	103,793.1
	PA	1,485,269.9	1,282,684.6	1,618,441.5	978,048.6	901,823.5
	VA	1,971,507.1	1,616,020.0	1,940,258.0	1,312,042.8	1,007,151.7
	WV	225,933.6	187,550.2	220,266.5	123,053.6	89,903.2
Basin	EAS	199,000.0	149,028.9	225,111.2	120,863.5	92,588.0
	JAM	783,834.0	632,511.9	757,264.7	507,003.6	350,112.0
	POT	1,492,096.1	1,273,573.8	1,625,629.1	972,137.3	733,769.5
	RAP	442,833.2	376,087.5	424,111.7	343,374.0	316,823.4
	SUS	1,549,106.2	1,312,990.8	1,620,693.7	1,038,093.2	910,161.7
	WES	155,852.8	119,188.4	162,086.7	102,495.6	52,623.1
	PAT	94,467.9	57,009.5	78,816.1	51,354.5	30,231.0
	YOR	104,529.1	70,846.0	98,381.0	55,621.9	40,836.8
Chesapeake Bay Total (tons/year)						
		4,820,000	3,990,000	4,990,000	3,190,000	2,530,000

Table 12-5. Delivered total allocation loads (million lbs/year) by state basin

		Draft Allocation (nitrogen)	Draft Allocation (phosphorus)	Draft Allocation (TSS) (range)
Eastern Shore (EAS)				
	DE	2.95	0.26	58–64
	MD	9.71	1.09	166–182
	PA	0.28	0.01	21–23
	VA	1.21	0.16	11–12
James River Basin (JAM)				
	VA	23.48	2.34	837–920
	WV	0.02	0.01	15–17
Potomac River Basin (POT)				
	DC	2.32	0.12	10–11
	MD	15.70	0.90	654–719
	PA	4.72	0.42	221–243
	VA	17.46	1.47	810–891
	WV	4.67	0.74	226–248
Rappahannock River Basin (RAP)				
	VA	5.84	0.90	681–750
Susquehanna River Basin (SUS)				
	MD	1.08	0.05	60–66
	NY	8.23	0.52	293–322
	PA	71.74	2.31	1660–1826
Western Shore (WES)				
	MD	9.74	0.46	155–170
	PA	0.02	0.001	0.37–0.41
Patuxent River Basin (PAT)				
	MD	2.85	0.21	82–90
York River Basin (YOR)				
	VA	5.41	0.54	107–118
Totals (million lbs/year)				
State	DC	2.32	0.12	10–11
	DE	2.95	0.26	58–64
	MD	39.09	2.72	1,116–1,228
	NY	8.23	0.52	293–322
	PA	76.77	2.74	1,903–2,093
	VA	53.40	5.41	2,446–2,691
	WV	4.68	0.75	241–265
Basin	EAS	14.15	1.53	256–281
	JAM	23.50	2.35	852–937
	POT	44.88	3.66	1,920–2,113
	RAP	5.84	0.90	681–750
	SUS	81.06	2.88	2,013–2,214
	WES	9.76	0.46	155–171
	PAT	2.85	0.21	82–90
	YOR	5.41	0.54	107–118
Bay Total (million lbs/yr)				
		187.44	12.52	6,066–6,673

12.6 Climate Change Estimated Effect on Nutrient and Sediment Loads

During the last century, the Chesapeake Bay watershed, like much of the United States, experienced warming temperatures, increases in precipitation, and increases in the average intensity of precipitation events (Karl and Knight 1998; Najjar et al. 1999; Najjar et al. 2000; Cronin et al. 2003; Milly et al. 2008). Projections of future climate suggest such trends are likely to continue and, in many cases, intensify (Tebaldi et al. 2006; Union of Concerned Scientists 2006; Najjar et al. 2009). Water resources and aquatic ecosystems are highly vulnerable to those changes with possible effects including increased occurrence of floods and droughts, water quality degradation, channel instability and habitat loss, and effects on aquatic biota (Fisher et al. 2000; Pyke et al. 2008).

The Chesapeake Executive Order (Office of the President 2009) has specified a reassessment of the Chesapeake Bay restoration in 2017 that will explicitly include an assessment of climate change influences. Water managers in the Chesapeake Bay watershed face significant challenges associated with climate change and the effects of land use, increases in water demand, ecosystem degradation, and other stressors (Gibson and Najjar 2000; Neff et al. 2000). Some stressors interact in ways that reinforce detrimental effects. For example, increased population with increases in imperious area results in warmer, flashier runoff, which reinforces similar climate change effects. In 2017 the CBP will examine climate change to explicitly determine the scope, magnitude, and timing of potential effects. An improved understanding of climate change effects through an extension of the CBP model capabilities will enable CBP water managers to better evaluate risk and make informed decisions about meeting supply needs, complying with water quality regulations, and protecting aquatic ecosystems over a range of time scales (Cronin 2000; Willard et al. 2003; Cronin et al. 2005; Cronin and Walker 2006; DeCandis and Najjar 2006; Saenger et al. 2006).

The initial assessment of climate change in the Chesapeake Bay reported in this report was supported by use of tools developed for EPA's BASINS 4 system including the CAT http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203460 (USEPA 2009). Flows and associated nutrient and sediment loads were assessed in all river basins of the Chesapeake Bay with three key climate change scenarios reflecting the range of potential changes in temperature and precipitation in the year 2030. The three key scenarios came from a larger set of 42 climate change scenarios that were evaluated from 7 GCMs, 2 scenarios from the IPCC SRES storylines, and 3 assumptions about precipitation intensity in the largest events. The 42 climate change scenarios were run on a version of the Phase 5 Watershed Model of the Monocacy, a subbasin of the Potomac in the Piedmont region, using a 2030 estimated land use based on a sophisticated land use model containing socioeconomic estimates of development throughout the watershed.

Downscaled GCM temperature and precipitation data sets were provided by Consortium for Atlantic Regional Assessment (http://www.cara.psu.edu/). Weather data reflecting each climate change scenario for input to the model were created by modifying a 16-year period of historical data of precipitation and temperature from 1984 to 2000 on a seasonal basis for each National Climate Data Center (NCDC) weather station used as input to the model to reflect the changes projected in each of the three key scenarios.

12.6.1 The BASINS Climate Assessment Tool

EPA's BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) is a multipurpose environmental analysis system designed for use by regional, state, and local agencies performing watershed and water quality-based studies. The system makes it possible to quickly assess large amounts of data in a format that is easy to use and understand. BASINS integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to watershed management and environmental protection. BASINS version 4.0 is the first to be primarily based on a nonproprietary, open-source GIS foundation. The BASINS modeling system, thus, offers a unique platform on which to develop additional tools useful to stakeholders concerned with climate change.

The design and capabilities of a new Climate Assessment Tool (CAT) released with BASINS 4.0 facilitates the assessment of the influence of climate variability and change on a range of hydrologic and water quality endpoints (USEPA 2009). As used here, an endpoint is any hydrologic or water quality characteristic that can be calculated using output from the watershed models in BASINS. Examples include mean annual streamflow, annual water yield, a 100-year flood event, a Q7-10, mean annual nutrient concentration, annual nutrient or sediment load, and maximum daily contaminant concentration. The CAT also facilitates the assessment of adaptation strategies (e.g., BMPs) for increasing the resilience of different endpoints to climate variability and change.

Specific capabilities of the CAT include the ability to modify historical climate, generate synthetic weather time series, and conduct systematic sensitivity analyses for specific hydrologic and water quality endpoints using the BASINS models. For example, users can manipulate climate variables to change long-term mean, variability, monthly or seasonal characteristics, and the occurrence of individual *design* events. Those changes in climatic parameters are then converted to modified meteorological time series, either through manipulation of historical observations or simulation using an embedded weather generator. Meteorological time series can be exported or used to drive BASINS hydrologic models, including HSPF (Bicknell et al. 1997; 2001; Donigian et al. 1984; Johanson et al. 1980).

In addition, the CAT can operate in an iterative mode to conduct systematic sensitivity analyses for specific hydrologic endpoints. In that mode, the tool iteratively manipulates the meteorological inputs, runs the hydrologic model, and manages output. The result is a profile of hydrologic responses to changes in two-dimensional combinations of climatic variables such as temperature and precipitation. That information will help water managers and other stakeholders understand the sensitivity of specific endpoints to prospective changes in climate. An understanding of sensitivity is a necessary foundation for conducting watershed-scale vulnerability analyses.

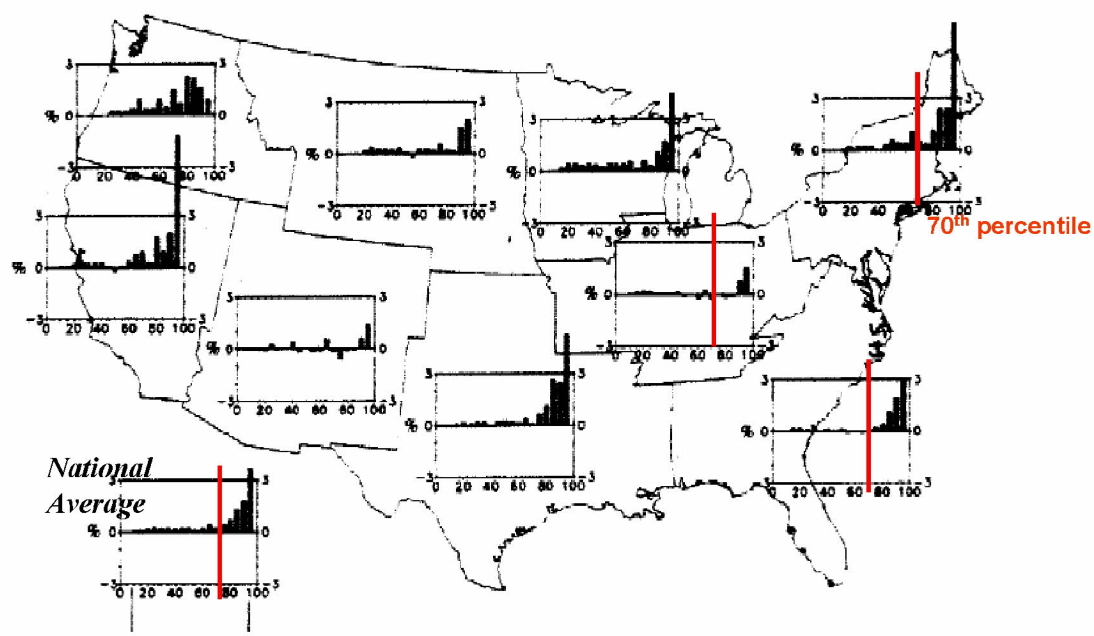
BASINS was used to examine the full suite of 423 scenarios in the Monocacy watershed of the Potomac basin and for developing three scenarios for the entire Chesapeake watershed.

12.6.2 Selecting Three Key Watershed-Wide Climate Change Scenarios

The 42 scenarios run on the Monocacy were narrowed down to 9 scenarios, which were then run on the full Chesapeake watershed using as a base scenario of the 2000 Scenario (Linker et al. 2000). The 2000 Base Scenario has all land use, point source flows, and populations of the year

2000 and was run with a 10-year average hydrology of 1991 to 2000 (Johnson and Weaver 2008).

A key determinant of flows and loads in the climate change simulations was changes in precipitation treatment. On the basis of historical precipitation records and GCM outputs, the trend for precipitation is for greater precipitation intensity at the highest 30 percent of events, which was represented in the scenarios by a *flash 30%* precipitation treatment, in which the precipitation increases were applied to only the highest 30% of precipitation events (Figures 12-30 and 12-31). Other studies provide evidence that precipitation trends could be moving toward an increase in intensity in the highest 10 percent of events, represented by a *flash 10%* precipitation treatment (Karl and Knight 1998). There is considerable uncertainty in the precipitation estimates of the GCMs, so three assumptions about precipitation treatments were used to represent the predicted increase in precipitation by the GCMs, a flash 30%, a flash 10%, and a constant precipitation increase as represented in Figure 12-31.



Source: Karl and Knight 1998

Figure 12-30. Observed trends in precipitation by size class (percent change in precipitation per century, 1910–1996)

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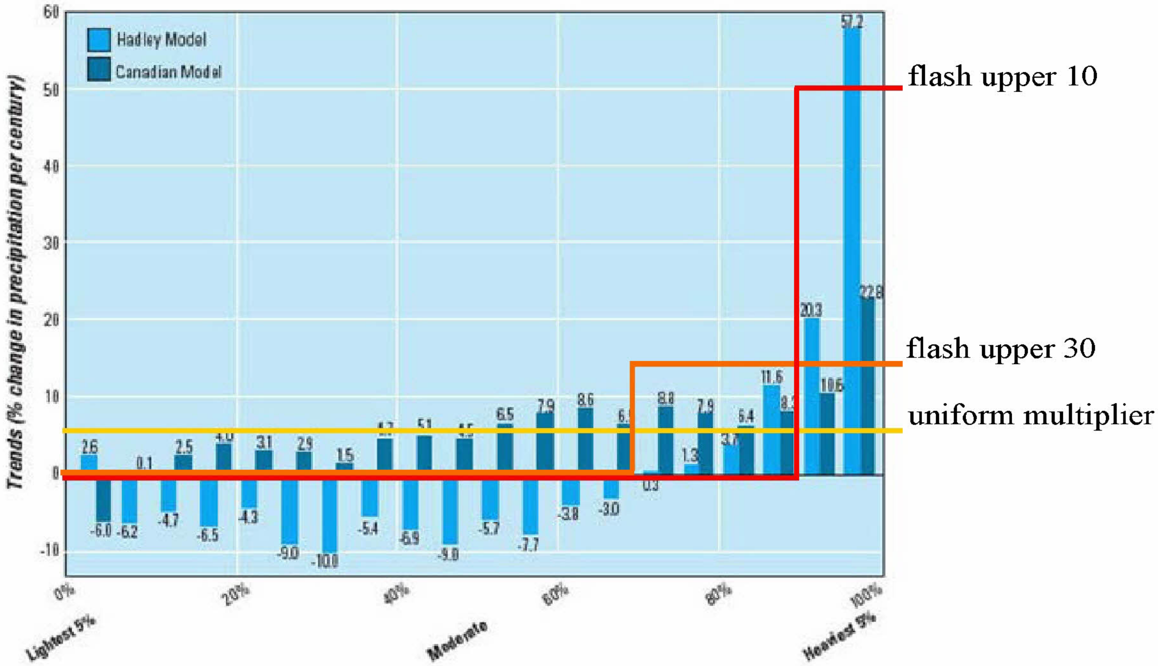

Figure 12-31. Representation of different methods of modifying precipitation in the Chesapeake climate change study (percent change in precipitation per century, simulated with the Hadley and Canadian GCMs).

The 42 initial scoping scenarios in the Monocacy watershed provided a basis for choice among the three precipitation treatments of the highest, lowest, and median nitrogen load estimates of each precipitation treatment. Because nitrogen load was a key driver of the key driver of Chesapeake Bay hypoxia, that was the outcome on which the initial assessment was focused. With the high, low, and median nitrogen loads of each precipitation treatment selected, the resulting nine scenarios were then run on the full watershed (Linker et al. 2000) with the results represented as a percent difference from the Base 2000 Scenario shown in Table 12-6. To run the climate change scenarios on the full Phase 5 Watershed Model, the relative change in precipitation and temperature for each of the GCMs were applied to the 10-year time series of precipitation and temperature in the watershed model. With the precipitation data, the time series was adjusted either uniformly, or only adjusted in the top 30 percent of events (flash 30%), or only adjusted in the top 10 percent of events (flash 10%)

Table 12-6. Summary of the max, min, and median values of the nine full Chesapeake Bay watershed test scenarios

Scenario - GCM - *Emission Projection*	FLOW	TN	TP	TSS
Flash 10 High - **ECHM** - *B2*	-0.6%	3.7%	4.1%	75.7%
Flash 10 Middle - **GFDL** - *B2*	-6.0%	0.6%	0.7%	21.9%
Flash 10 Low - **CSIRO** - *A2*	-12.9%	-4.8%	-7.4%	-7.0%
Flash 30 High - **NCAR** - *A2*	4.5%	3.3%	7.8%	21.3%
Flash 30 Middle - **HADC** - *B2*	-4.8%	-1.6%	-2.1%	4.9%
Flash 30 Low - **CSIR** - *B2*	-13.1%	-5.7%	-9.4%	-15.1%
Uniform Factor High - **NCAR** - *A2*	5.0%	3.2%	5.2%	7.3%
Uniform Factor Middle - **CCSR** - *B2*	-6.4%	-2.4%	-4.8%	-5.4%
Uniform Factor Low - **CSIRO** - *A2*	-14.0%	-6.1%	-10.2%	-20.5%
Minimum	**-14.0%**	**-6.1%**	**-10.2%**	**-20.5%**
Maximum	**5.0%**	**3.7%**	**7.8%**	**75.7%**
Median	**-6.0%**	**-1.6%**	**-2.1%**	**4.9%**

Of the nine full watershed scenarios run, three are represented below as an annual average time series of flows or loads in the Susquehanna River. The three scenarios are (1) CSIRO—Australia's Commonwealth Scientific and Industrial Research Organization using the A2 emission scenario and the uniform participation factor, which had the lowest overall flow, and loads of total nitrogen, total phosphorus and total suspended sediment compared to the 2000 Base Scenario; (2) ECHM—German High Performance Computing Centre for Climate and Earth System Research using the B2 emission scenario and the *flash 10* participation factor, which had the highest total nitrogen and total suspended solids loads compared to the 2000 Base Scenario; and (3) HDCM—Hadley Centre for Climate Prediction and Research using the B2 emission scenario and the *flash 30* precipitation factor, which had an intermediate response.

12.6.2 Initial Climate Change Findings

Three key climate change scenarios covering low, medium, and high nitrogen load outcomes affecting factors influencing Chesapeake water quality standards are assessed below. The application of low, medium, and high climate change effects for the climate change 2030 condition provides an early look at the Chesapeake Bay Program's assessment of the TMDL water quality standards of dissolved oxygen, chlorophyll, and water clarity and what is needed to achieve and maintain the standards at a 2030 future condition. Future assessments will include the tidal Bay response in dissolved oxygen, chlorophyll, and clarity, which can be estimated by linking the climate change scenarios with the Chesapeake Water Quality and Sediment Transport Model.

Factors influencing the water quality standards are nutrient and sediment loads. Nutrient loads of nitrogen and phosphorus are important for the dissolved oxygen and chlorophyll standards, and sediment influences the Bay's clarity standard. The Bay has long residence times, which are on the order of about 9 months for dissolved material entering head of the Bay during a average year. Inorganic and labile nutrients would have longer transit times because of biological uptake and cycling. As a result, the Bay is relatively insensitive to the seasonal loads for nutrients, i.e., equivalent winter or summer loads of nutrients are roughly equivalent in generating dissolved oxygen or chlorophyll standard violations as shown in model runs using the 2002 Chesapeake Water Quality Model (Cerco and Noel 2004). Nitrogen loads are largely determined by the magnitude of the annual flows, but phosphorus and sediment are influenced peak flows and scouring of phosphorus and sediment from land surfaces and within river systems.

Sediment is also more effectively delivered to the Bay in peak or storm flows, which scour sediment from the land surface and from stream and river beds. The effect of sediment is primarily on water clarity, which is a standard designed to protect and restore submerged aquatic vegetation (SAV). As the clarity standard is effective during the SAV growing season only, the effects of sediment loads would be weighted toward the spring, summer, and early fall. The key period of the clarity standard is in effect from April to October.

The Susquehanna River basin covers almost half the Chesapeake Bay watershed and has a major influence on flows and loads to the Chesapeake. The Susquehanna was examined with an annual average time series of flows and loads reported as a percent difference of the 2030 climate scenarios to the 2000 Base Scenario. Generally, flows were seen to decrease in the climate change scenarios despite the higher climate change precipitation inputs because of the increased temperature and resulting increases in the simulated watershed evapotranspiration.

In the Chesapeake Bay watershed, 2030 estimated temperatures are about 1.5 °C higher over the current temperatures. That estimate is relatively consistent in the different GCMs and has a high degree of certainty. Estimated precipitation increases among the seven GCMs are about 2 percent over current conditions, especially at higher rainfall events, and it is estimated with a moderate degree of certainty. How those temperature and precipitation increases affect flow and associated nutrient and sediment loads in the watershed hangs in a hydrologic balance between precipitation and evapotranspiration (Figure 12-32).

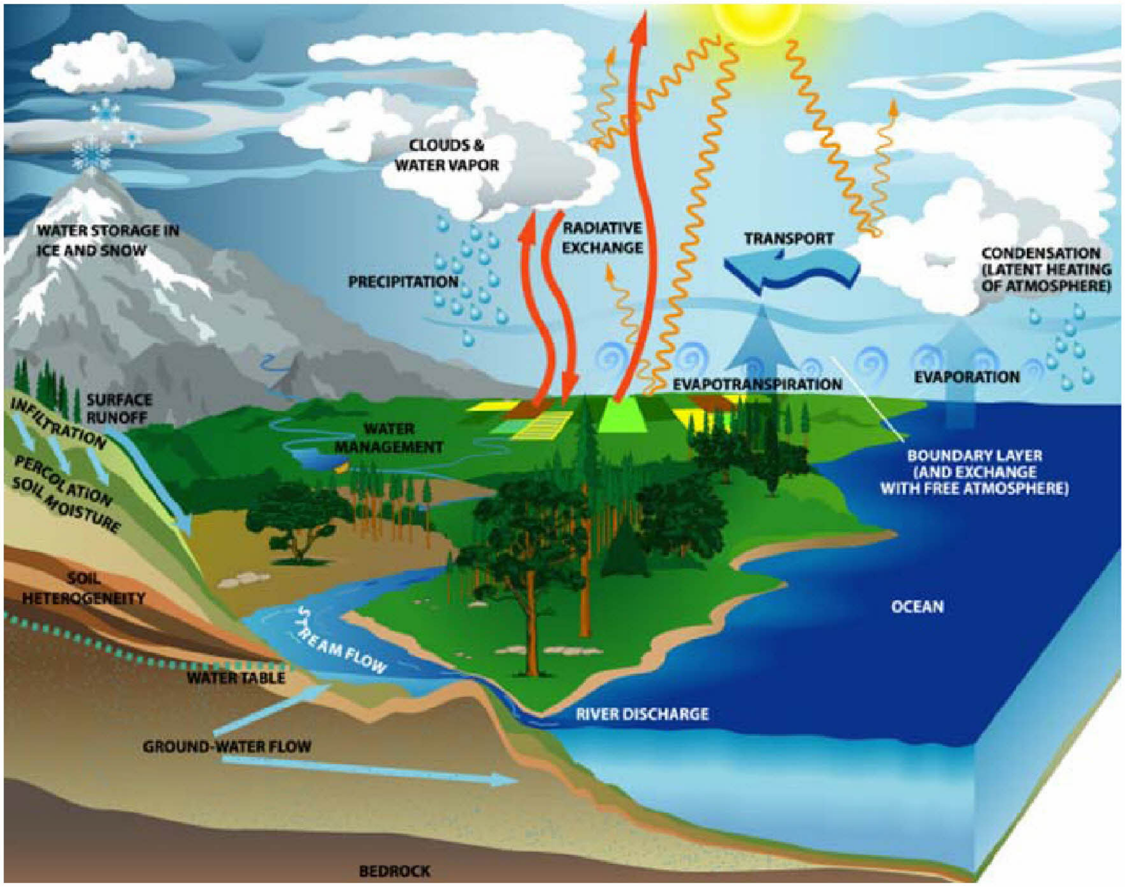

Figure 12-32. About half the precipitation input to the Chesapeake Bay watershed is lost through evapotranspiration, a process that is enhanced with increased temperature.

Temperature increases tend to increase evapotranspiration in watersheds and can offset increases in precipitation. That seems to be the case in the Chesapeake Bay watershed. Estimates of the medians of the nine different scenarios run have an annual average flow, nitrogen, and phosphorus load decrease of –6 percent, –2 percent, and –2 percent, respectively (Table 12-6). Because sediment loads increase with higher rainfall events, the median of the nine scenario estimates for sediment is for an increase of 5 percent. Figures 12-33 to 12-35 show annual average time series of flow, nitrogen and sediment loads for the three climate change scenarios compared to the 2000 Base Scenario.

For all three scenarios, flow is decreased in the high-flow winter period, although for two of the scenarios, summer flows are higher (Figure 12-33). That could be due to the flash 30% and flash 10% precipitation conditions used in the scenarios combined with summer precipitation patterns, which are characterized by short-term, high-precipitation, thunderstorm events. Total nitrogen loads follow the overall flow conditions, and they are generally depressed in the winter high-load period of nitrogen (Figure 12-34).

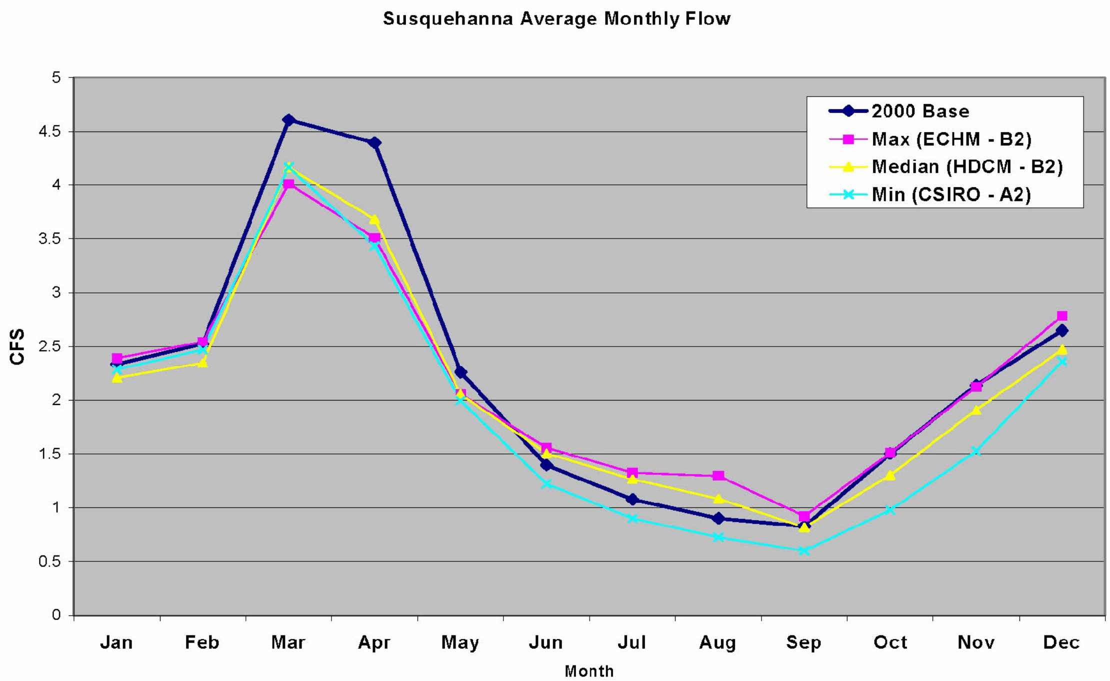

Figure 12-33. Average annual time series of flow in cubic feet per second of the 2000 Base Scenario and the three high, median, and low climate change scenarios.

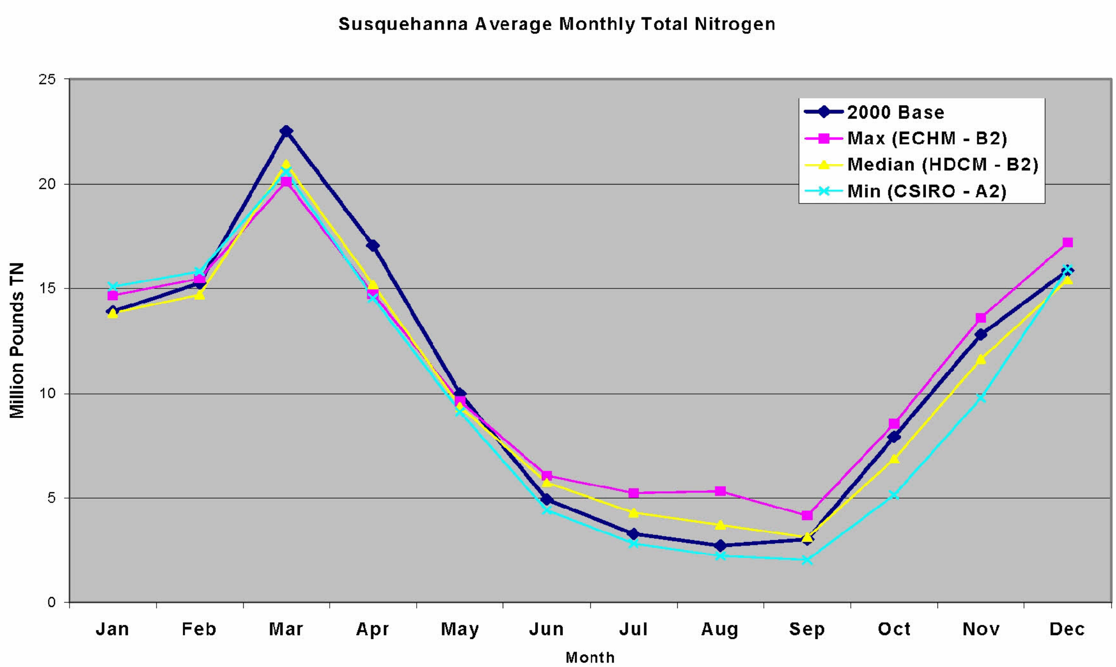

Figure 12-34. Average annual time series of total nitrogen in millions of pounds of the 2000 Base Scenario and three high, median, and low climate change scenarios.

The total phosphorus time series is similar to total nitrogen, although it is somewhat more responsive to episodic summer high flows in the two flash 10% and flash 30% precipitation conditions (Figure 12-35).

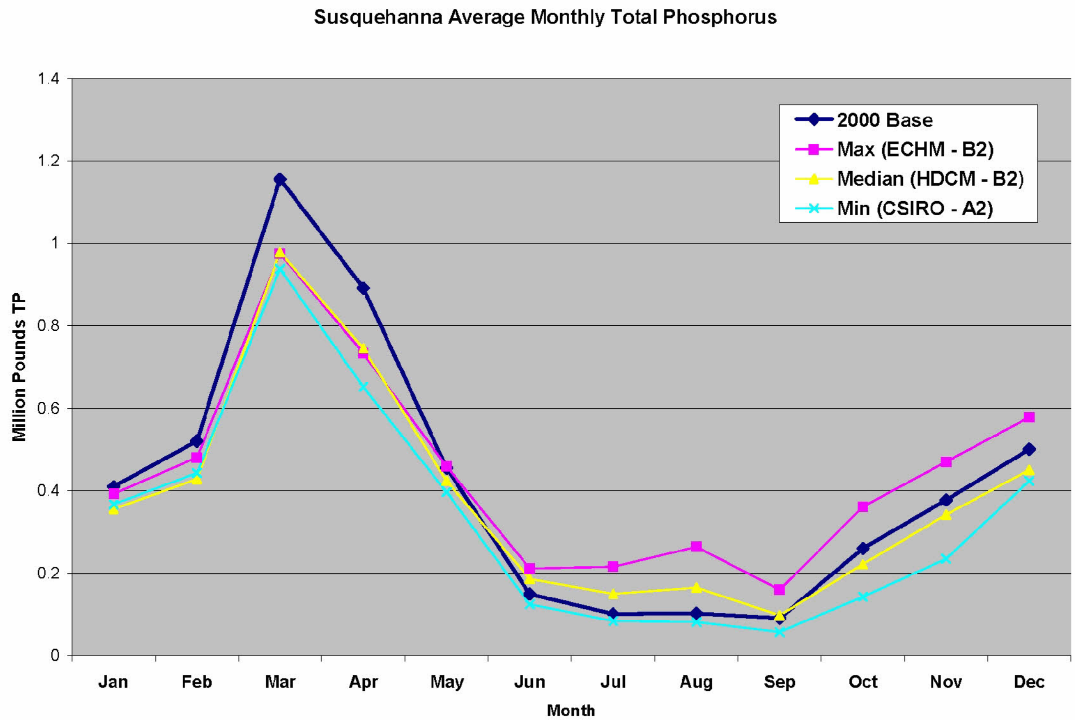

Figure 12-35. Average annual time series of total phosphorus in millions of pounds of the 2000 Base Scenario and three high, median, and low climate change scenarios.

In the Chesapeake Bay watershed, the concentration of TSS can increase three orders of magnitude from low flow to extreme high flow conditions, particularly in the larger rivers. Combined with higher flows, the higher TSS concentrations generate estimates of TSS loads under the flash 10% and flash 30% conditions that are episodic and flashy in nature (Figure 12-36).

Overall, the model findings show the potential range of response of flows and loads to climate change, at least over a relatively short planning horizon of 20 years. If the historic and model trends hold true with respect to precipitation trends increasing in the larger events, and if estimated increases in evapotranspiration with higher temperature outweigh estimated 2030 increases precipitation, implications for flow and nutrient loads in the Chesapeake are for relative declines on an annual average basis of flows and nutrient loads. However, sediment loads could increase.

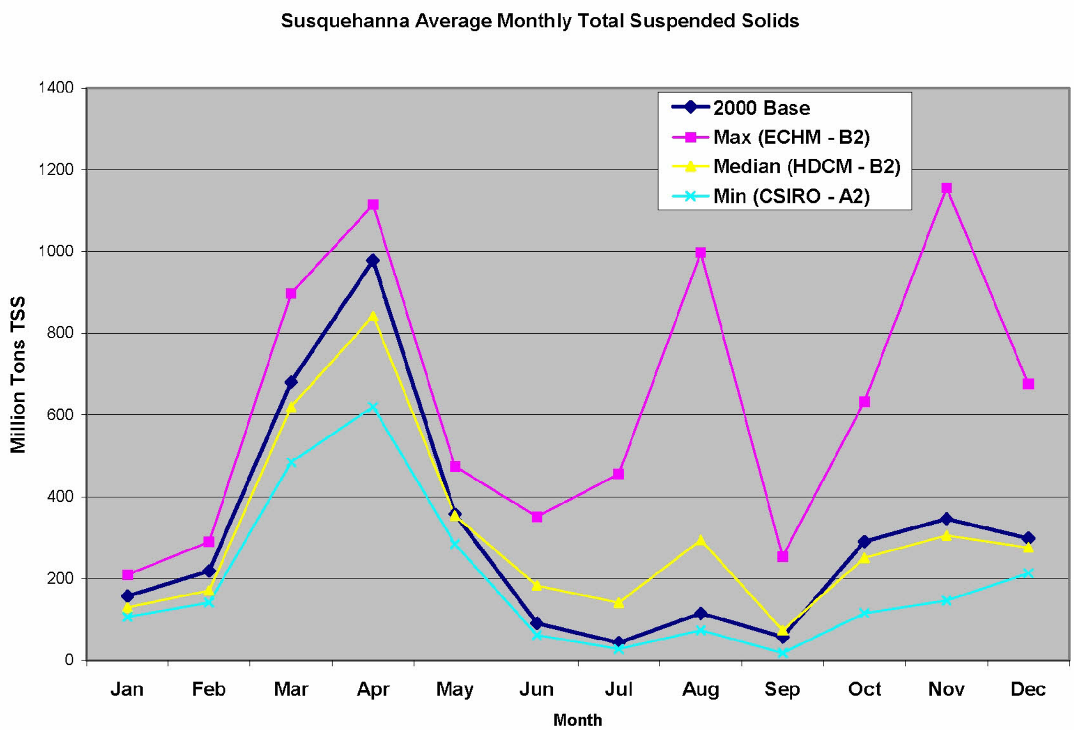

Figure 12-36. Average annual time series of total suspended solids in millions of tons of the 2000 Base Scenario and three high, median, and low climate change scenarios.

The climate is changing and that has significant long-term implications for the Chesapeake restoration. Planning for long-term Bay restoration could involve the consideration of new questions in the 2017 Assessment of the Chesapeake TMDL progress:

- What are the potential effects of climate change on water quality standards and living resources?
- How will the Chesapeake Watershed Implementation Plans (WIPs) and other management actions perform under changing climatic conditions?
- What are the broader implications for water resources, such as water supply and flood-control measures?

Climate change work will continue to be refined over the next several years as improved GCMs and downscaling techniques become available. Additional endpoints should also be examined such as peak flow, the influence of TSS loads on the clarity-SAV water quality standard, and the tradeoffs in nitrogen and phosphorus load changes and how it would influence Bay hypoxia. Changes in land use and the fungible nature of climate change and increased urbanization with associated increases in watershed imperviousness should also be examined.

The work demonstrates that in 2017, as called for in the Chesapeake Executive Order, the Chesapeake Bay integrated models of the watershed, estuary, and living resources with climate change tools can be used to examine climate change and related water resource issues to understand the Bay Program goals' vulnerability to climate changes.

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Revised December 27, 2010